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OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS

Vol. XXXV Number 7

JULY, 1916

Pacific Coast Convention, Sept. 5-9, 1916

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PACIFIC COAST CONVENTION

OF THE

American Institute of Electrical Engineers

Seattle, Wash., Sept. 5-9, 1916

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PROCEEDINGS

Vol. XXXV JULY, 1916 Number 7

PACIFIC COAST CONVENTION, SEATTLE, SEPTEMBER 5-9, 1916

The annual Pacific Coast Convention of the American Institute of Electrical Engineers will be held this year in Seattle, Wash., September 5-9, inclusive. The Northwest Electric Light and Power Association will also hold its annual convention in Seattle, September 6-9, inclusive, and the program committees of the two organizations have planned so that conflicting sessions will be avoided, so far as is possible.

The headquarters for both gatherings will be at the Hotel Washington. The Institute convention will be called to order Tuesday morning, September 5, and after an address of welcome, the morning and afternoon sessions will be devoted to the subject of high-tension transmission. On Wednesday, September 6, a telephone session will be held in the morning, and a session on heating and domestic power in the evening. Wednesday afternoon and all day Thursday are to be left open for attendance at the meetings of the Northwest Association. Friday, September 8, will be given over to a round-table session and an executive meeting, and Saturday, September 9, to entertainment.

The entertainment program includes a joint banquet of both associations, automobile ride and lunch at the Boulevard Inn, theater party for the ladies, and a boat trip around Lake Washington.

Several interesting papers have already been received, and final announcement will shortly be made of the titles and authors. It is expected that the complete program for the convention will be ready for publication in the August PROCEEDINGS.

ILLUMINATING ENGINEERING SOCIETY CONVENTION

The tenth annual convention of the Illuminating Engineering Society is to be held in Philadelphia, September 18-21, 1916. The papers committee has arranged a program of papers of high quality, on a variety of subjects related to illuminating engineering.

Following the convention, from September 21 to 28 there will be given a course of some twenty lectures on illuminating engineering, under the joint auspices of the Society and the University of Pennsylvania. An announcement in regard to this lecture course was made in the June PROCEEDINGS.

THE CLEVELAND CONVENTION

The thirty-third Annual Convention of the American Institute of Electrical Engineers was held at the Hollenden Hotel, Cleveland, Ohio, June 27-30, 1916. The total number of members and guests in attendance was 607, including 108 ladies. The local registration from Cleveland numbered 288, and the remainder of those in attendance represented twenty-two states, while Canada, Panama, England, and India each had

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representatives. The Cleveland Convention will be remembered as one of the most successful of the Institute's annual conventions, both from technical and social standpoints, and a large part of the credit for this success is due to the excellent work of the Convention Committee under the chairmanship of Mr. E. H. Martindale, which not only made highly satisfactory plans for the comfort and entertainment of the members, but was actively employed during the convention in carrying out these plans. The weather conditions were also ideal during the week, being cool and fair.

Tuesday Morning

The convention was called to order at 10 o'clock Tuesday morning by President Carty, who introduced Mr. Floyd Waite, Secretary of the Department of Public Service of Cleveland, who represented Mayor Davis, who was absent from the city. Mr. Waite made an appropriate address of welcome, after which President Carty delivered his presidential address, taking as his subject "The Relation of Pure Science to Industrial Research." This address will be printed in full in a future issue of the PROCEEDINGS. President Carty then introduced Mr. C. le Maistre, General Secretary of the International Electrotechnical Commission, who read a brief paper entitled "Standardization," in which he outlined the development of engineering standards in Great Britain and the need of international standards and of some agreements in nomenclature and symbols for interpreting specifications offered by one country to another. Mr. le Maistre's paper was briefly discussed by Dr. C. H. Sharp, Dr. C. P. Steinmetz, and Mr. Farley Osgood, all of whom complimented Mr. le Maistre on his successful personal efforts in advancing international standardization. The rest of the Tuesday morning session was devoted to papers on industrial power subjects, Mr. David Hall presenting a paper on "Electric Drive for Reversing Rolling Mills" by Wilfred Syke and himself, after which Mr. W. G. Taylor read his paper on "Motor Equipment for the Recovery of Petroleum," both of which papers elicited considerable discussion.

Tuesday Afternoon

President Carty called the meeting to order at 2:30 p.m., at which time the Power Transmission Session was scheduled. The report of the Transmission Committee by Percy H. Thomas, chairman, was presented by Mr. N. A. Carle, in the absence of Chairman Thomas. This was followed by a paper by V. M. Montsinger on "Effect of Barometric Pressure on Temperature Rise of Self-Cooled Stationary Induction Apparatus," and a paper by Mr. F. E. Ricketts, "Restoring Service After a Necessary Interruption." Both of these papers were presented in abstract by their authors, to afford time for the lengthy discussion which followed.

Tuesday Evening

The dinner-dance which was scheduled for Tuesday evening was preceded by a reception held on the porch balcony of the Hollenden Hotel. In the receiving line were President and Mrs. J. J. Carty, Vice-President and Mrs. J. Franklin Stevens, President-elect Harold W. Buck, Honorary Secretary Ralph W. Pope, President Charles S. Howe of the Case School of Applied Science, and Secretary F. L. Hutchinson. About 250 members attended the banquet which followed the reception. The tables were arranged in the banquet hall so as to leave the center of the floor open for dancing. Several exhibition dances were given between courses by Miss V. N. Cotabish, a talented interpretive dancer of Cleveland. During the dinner Mr. Carty introduced President-elect Harold W. Buck, who made an interesting address. At the close of the dinner the party adjourned to the crystal room of the Hollenden Hotel, where dancing was enjoyed until midnight.

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Wednesday Morning

The session on Wednesday morning was under the auspices of the Protective Apparatus Committee, and six papers were presented, all but one of which were by members of this committee. Mr. D. W. Roper presented his paper on "Studies in Lightning Protection on 4000-Volt Circuits," which gave the method of and numerous statistics in regard to the protection of transformers on the distribution system of the Commonwealth Edison Company. The other five papers in this session, which were in the nature of committee reports, were presented by their authors as follows: "Experience in Recent Developments of Central Station Protective Features," by N. L. Pollard and J. T. Lawson; "Protection of High-Tension Distribution Systems by Isolating Transformers," by O. O. Rider; "Megger and Other Tests on Suspension Insulators," by F. L. Hunt; "Experiences in Testing Porcelain Insulators," by E. E. F. Creighton; "New Method of Grading Suspension Insulators," by R. H. Marvin.

Wednesday Evening

After a dinner at 6:30 p.m., the Board of Directors of the Institute held a meeting at the Hollenden Hotel Wednesday evening, June 28. The following resolutions were unaminously adopted at this meeting:

Resolved, that the Board of Directors of the American Institute of Electrical Engineers, representing the membership at large, and more especially the members and guests in attendance at the Annual Convention in Cleveland, hereby expresses its hearty appreciation of the excellent arrangements made by the local Convention Committee for the comfort and entertainment of the members and guests of the Institute during the convention, and

Resolved, that the thanks and appreciation of the American Institute of Electrical Engineers be likewise tendered the Cleveland Telephone Company, the National Lamp Works of the General Electric Company, the Shaker Heights Country Club, and the Mayfield Country Club.

Branch Delegates

At 8:00 o'clock p.m. a conference of the Student Branches was held. Professor C. Francis Harding, of Purdue University, presided at this meeting and several topics were discussed in relation to the work of the Student Branches and the relation of these Branches to the Institute, and recommendations embodying the sense of the conference were made for the consideration of the Board of Directors.

Section Delegates

The delegates of the Sections of the Institute, together with members of the Sections Committee and officers of the Institute, met for informal discussion at luncheon on Tuesday and Wednesday, and the regular scheduled conference of officers and delegates, which has come to be known as the "experience meeting," was held Wednesday evening at 8:30. A complete list of the delegates present is as follows:

Atlanta	A. M. Schoen
Baltimore	John B. Whitehead
Boston	George A. Burnham
Chicago	T. Milton
Cleveland	E. H. Martindale
Denver	W. A. Carter
Detroit-AnnArbor	A. S. Albright
Fort Wayne	E. A. Wagner
Indianapolis-Lafayette	J. L. Wayne, 3d.
Ithaca	A. M. Gray
Kansas City	George B. Shaad
Los Angeles	E. Woodbury
Lynn	G. N. Chamberlin
Madison	J. N. Cadby
Milwaukee	R. B. Williamson
Minnesota	E. T. Street
Panama	R. H. Whitehead
Philadelphia	J. H. Tracy
Pittsburgh	A. G. Pierce
Pittsfield	M. O. Troy
Rochester	E. L. Wilder
San Francisco	W. C. Miller, Jr.
Schenectady	L. T. Robinson
Seattle	C. F. Terrell
Spokane	Charles A. Lund
Toledo	M. E. Grah
Toronto	Edgar T. Brandon
Urbana	P. S. Biegler

Others in attendance at one or more of the Sections Committee conferences,

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were President J. J. Carty, President-elect H. W. Buck, Honorary Secretary Ralph W. Pope, Secretary F. L. Hutchinson; Frederick Bedell and H. W. Flashman, members of the Sections Committee; Mr. E. H. Whitlock, Chairman. A. S. M. E. Sections Committee, and several past chairmen and chairmen-elect of Sections. The proceedings at these meetings involved discussion of a wide range of subjects in connection with various Section activities, and a report of these meetings, with a résumé of the actions taken, will be prepared at a later date and forwarded to the delegates in attendance and the Section officers. This report will also be available upon application to the Secretary, to any Institute members who may be interested.

Thursday Morning

Thursday morning was devoted to the presentation of the three papers presented under the auspices of the Electrophysics Committee. Mr. F. W. Peek, Jr., presented his paper on "Effect of High Continuous Voltage on Air, Oil, and Solid Insulation;" Dr. J. B. Whitehead presented a paper by himself and Mr. M. W. Pullen on "The Corona Voltmeter;" and Mr. E. E. F. Creighton presented a paper on the "Theory of Parallel Grounded Wires and Production of High Frequency in Transmission Lines." All the papers were presented briefly in abstract, to permit of sufficient time for the full discussion which followed.

Friday Morning

The technical session on Friday morning was called to order by President Carty at 10:00 a.m., on the *City of Erie*, during the all-day boat trip. The first paper of the session, by V. Karapetoff, was entitled "Suggestions for Electrical Research in Engineering Colleges," and in the absence of the author was presented by Professor Alexander M. Gray, and drew out considerable discussion. The next paper, by A. E. Kennelly and O. R. Schurig, entitled "Tractive Resistances to a Motor Delivery Wagon on Different Roads and at Different Speeds," was presented by title only in the absence of the authors. The last paper, "Application of a Polar Form of Complex Quantities to the Calculation of A-C. Phenomena," was abstracted by the author, Mr. N. S. Diamant, and the long discussion which followed brought the technical sessions to an end.

Entertainment

The numerous entertainment features arranged by the Convention Committee were well attended and greatly enjoyed by all present. On Tuesday at noon, 78 of the visiting and local ladies attended a luncheon at the store of Halle Brothers Company, which was followed by a trip of inspection through this store and through the stores of Kinney and Levan, Sterling and Welch, and the May Company.

On Wednesday afternoon over 350 members and guests were taken for an automobile trip through the beautiful parks and residence districts of the East Side, then along Lake Shore Boulevard and through the beautiful Shaker Heights residence district. There were 69 cars donated by members and friends of the Cleveland Section which took part in the parade, and the Automobile Committee obtained the full cooperation of the Cleveland police force which enabled the 69 machines with their 350 passengers, besides the drivers, to be loaded in 24 minutes.

On Wednesday evening 135 ladies saw the play, "A Happy Thought," at the Colonial Theater, this being its first production on any stage.

On Thursday afternoon special street railway two-car trains left the Hollenden Hotel at 1:30 for Nela Park, where 450 people enjoyed various outdoor games, including baseball, tennis, golf contests, and other athletic sports. At six o'clock 375 people assembled in the commodious dining room at Nela Park and partook of an excellent serve-self dinner. An excellent orchestra,

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which furnished music for the dinner-dance, was on hand all the afternoon and during the dinner at Nela Park. At the close of the dinner Mr. Carty was presented with a Past-President's badge, Vice-President Farley Osgood making the presentation speech. Six sight-seeing automobiles together with a number of private cars then carried the entire party to the Shaker Heights Country Club, where the evening was spent. This clubhouse is one of the handsomest buildings of its kind in Cleveland, and the wide veranda with its club service and generous supply of cigars and punch, divided the attractions with the beautiful ballroom where dancing was enjoyed all the evening. Special street railway cars took the members and guests back to the Hollenden Hotel at the close of a most enjoyable day.

The last day of the convention was spent on an all-day boat trip, for which the *City of Erie* was chartered to leave Cleveland for Put-in-Bay at 9:30 a.m. A delay of about fifteen minutes in starting was made to accommodate some late arrivals. A delightful day on the boat was enjoyed by 474 members and guests. As this boat is regularly used on night service between Cleveland and Buffalo, the dining room facilities were insufficient to take care of so many people, and arrangements were therefore made with an outside caterer who brought all of his equipment on board. The main deck was cleared, long tables set, and a fish dinner served at 12:30 to the entire party. A short stop was made at Put-in-Bay, where the new Perry monument commemorating the memorable victory of Lake Erie rises 385 feet in the air. Dancing and card games were enjoyed all the afternoon, and the prizes which were won throughout the convention were presented to the winners on the boat at 4:30 by the chairman of the Convention Committee. The boat returned to Cleveland on schedule time, which enabled the members and guests to leave Cleveland on the best trains for the East, West, and South.

Baseball

The annual baseball game, at Nela Park on Thurdsay afternoon, between the "Neverwases," Captain Osgood, and the "Hasbeens," Captain Hall, resulted in a victory for the "Hasbeens" with a score of 12-11. The game was ably and impartially umpired by Mr. L. T. Robinson, of Schenectady, assisted by Mr. N. A. Carle, who umpired the bases. The large and enthusiastic audience which witnessed this game unanimously declared it a most unique performance in the line of baseball; many of the plays baffled description—the game should have been seen to be appreciated. The prizes awarded were as follows: longest hit, R. F. Strickland; most hits, C. T. Mosman; most runs, L. P. Crecelius; most errors, J. H. Payne; best man rooter, L. T. Robinson; best lady rooter, Mrs. J. Franklin Stevens.

Prize Contests

The prizes for the various events were awarded as follows:

Golf Contest: First prize, L. F. Deming; second, J. R. Hewett; lowest score without handicap, L. F. Deming.

Ladies' Driving: First prize, Miss Merriman; second prize, Mrs. N. A. Carle.

Approaching and Putting: Men, first prize, A. M. Schoen; second, M. O. Troy. Putting: Ladies, first, Mrs. N. A. Carle; second, Mrs. F. W. Bedell.

Mr. Deming's victory entitles him to have his name engraved on the Mershon Golf Trophy. This cup becomes the property of any person wining the golf tournament in two different years at the Institute convention. It has previously been won by Mr. A. M. Schoen, of Atlanta, Mr. J. H. Livsey, of Detroit, and Mr. E. W. Allen, of Chicago.

Ladies' Card Party. Bridge: first, Miss Brewster; second, Mrs. Sohl;

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third, Mrs. Kirby. Five Hundred: first, Mrs. L. D. Bale; second, Mrs. S. M. Spindle.

Ladies' Baseball Throwing Contest: First, Miss M. Spencer; second, Mrs. C. R. Underhill.

Blowing Contest. Ladies: Mrs. E. H. Martindale, Miss M. Rowell, Mrs. C. R. Underhill, Mrs. Glick, Mrs. H. V. Bozell, and Mrs. Scott. Men: C. R. Underhill, H. V. Bozell, C. B. Hoffman, G. Lindstrom, Mr. Snyder, and C. F. Ripley.

Ladies' One-yard Race: First, Mrs. F. M. Hibben; second, Mrs. H. V. Bozell.

Tennis Tournament. Singles: first, C. W. Place; second, C. A. Berry. Doubles: W. L. Warren and C. A. Berry.

VISIT OF MR. C. LE MAISTRE TO THE UNITED STATES

As announced in the June issue of PROCEEDINGS, Mr. C. le Maistre, general secretary of the International Electrotechnical Commission, arrived in New York on May 12, as a delegate of the Engineering Standards Committee of Great Britain to meetings of the Standards Committee of the Institute.

On Friday evening, June 16, a dinner was given at the Engineers' Club, New York, in honor of Mr. le Maistre, by the officers and past-presidents of the Institute. Those present, in addition to the guest of the evening, included five past-presidents, twelve officers of the Institute, President-elect Buck, and twelve members of the Standards Committee and U. S. National Committee of the I. E. C.

President Carty acted as toastmaster, and brief addresses were made by Messrs. C. A. Adams, C. O. Mailloux, F. B. Crocker, H. G. Stott, Charles F. Scott, H. W. Buck, Gano Dunn, C. E. Skinner, H. M. Hobart, B. A. Behrend, Farley Osgood and Mr. le Maistre. Matters relating to standardization and to other subjects concerning the welfare and development of the engineering profession were discussed.

The occasion was exceedingly enjoyable to all present and will tend to strengthen the cordial relations existing between the engineering societies in this country and abroad.

Mr. le Maistre arranged to prolong his stay in America sufficiently to enable him to attend the Annual Convention of the Institute at Cleveland, where, upon the invitation of the Institute, he delivered an exceedingly interesting address on Standardization at the opening session, Tuesday, June 27.

BIBLIOGRAPHY ON VALUATION OF PUBLIC UTILITIES

The Committee on Valuation of the American Electric Railway Association has had compiled a "Bibliography on Valuation of Public Utilities." The work was done by the library force of the American Society of Civil Engineers, and brings up to December 23, 1915, a bibliography issued by the American Society of Civil Engineers on May 15, 1912.

The bibliography has been printed and issued by the American Electric Railway Association, 8 West Fortieth Street, New York, N. Y., and may be obtained from its Secretary on payment of 50 cents.

References are arranged under the following headings: General; Electric Light and Power; Gas Works; Mining; Railroads; Steam Power; Street and Interurban Railways; Telegraph and Telephone; Water Power; Water Works.

References are given to the principal technical publications, various works on the question of valuation, and to rules and regulations of commissions, and other official bodies, and the proceedings of the various societies.

Undoubtedly the compilation is the most comprehensive that has yet been published.

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PHOTOGRAPHIC DUPLICATING MACHINE INSTALLED BY LIBRARY

In order to increase the usefulness of the library, the United Engineering Society has installed a photographic duplicating machine for the reproduction of pages from books and periodicals, maps and charts in the Library of the Engineering Societies, and it is now in operation. Orders may be sent to the Library of the Engineering Societies, Engineering Societies Building, New York.

The process produces a photograph (white on black) direct on bromide paper, and from this negative print a positive may be made by re-photographing. The charge for a print 11 by 14 inches, which may cover two pages of an octavo volume which face each other, is 25 cents for a negative print and 50 cents for a positive print. Enlargements and reductions up to 11 by 14 inches are easily made. The process has the advantage of accuracy and cheapness.

PAST SECTION MEETINGS

Boston.—May 16, 1916, Franklin Union. Election of officers for the ensuing year as follows—chairman, George A. Burnham; vice-chairman, Harry M. Hope; secretary-treasurer, Ira M. Cushing.

Cleveland.—May 15, 1916, Hollenden Hotel. Addresses by Messrs. Lewis, Henderson, Susman, Jones, David and MacCutcheon on "Motor Troubles, the Cause, the Cure." Election of officers for the coming year as follows—chairman, E. W. P. Smith; secretary-treasurer, Bruce W. David. Attendance 43.

Detroit-Ann Arbor.—May 19, 1916, Ann Arbor. Address on "Electrical Precipitation of Smoke and Fumes," by Prof. Albert H. White. Attendance 55.

June 9, 1916, Detroit Engineering Society Hall. Paper: "Generation and Distribution of Power at the Ford Motor Company," by Fred Allison. Attendance 100.

Election of officers for the coming year as follows—chairman, A. A. Meyer; vice-chairman, H. H. Higbie; secretary-treasurer, A. Oakes; asst. secretary-treasurer, A. H. Lovell.

Denver.—May 27, 1916, University of Colorado. Dinner, followed by inspection of apparatus at the University of Colorado. Attendance 53.

June 17, 1916, Denver Athletic Club. Annual Meeting. Election of officers for the coming year as follows—chairman, H. S. Sands; vice-chairman, Norman Read; secretary-treasurer, Robert B. Bonney. Attendance 18.

Indianapolis-Lafayette. — May 25, 1916, Indianapolis. Paper: "Lightning Protective Apparatus," by F. H. Nealis. Attendance 35.

Kansas City.—May 31, 1916, Y.M.C.A. Building. Papers: "Faure Batteries for Small Isolated Plants," by R. H. Barber; "Industrial Preparedness," by George C. Shaad. Attendance 28.

Los Angeles.—May 16, 1916, Chamber of Commerce Bldg. Paper: "Some Engineering Experiences in the Orient," by G. A. Reichard. Attendance 32.

Lynn.—May 24, 1916, Assembly Hall. Annual Meeting of Section. Election of officers for the coming year as follows—chairman, Gordon M. Campbell; secretary-treasurer, Morris B. Carroll; executive committee, F.H. Bowman and F. W. Mace. Address by Mr. A. L. Hawkins on "The Schenectady Research Laboratories". Attendance 150.

Madison.—May 16, 1916, Engineering Bldg., University of Wisconsin. Election of officers for the coming year as follows—chairman, F. A. Kartak; secretary-treasurer, L. E. A. Kelso. Address by Prof. Edward Bennett on "The Properties of Loaded and Unloaded Telephone Lines." Attendance 26.

Milwaukee.—May 25, 1916, Republican House. Address by Dr. D. J. Jacobus on "The Relation of the Sections to the National Engineering Societies." Meeting under auspices of local section of A. S. M. E. Attendance 50.

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June 21, 1916, Republican House. Election of officers for the ensuing year as follows—chairman, F. W. Ells; secretary, H. P. Reed. Illustrated address by Mr. Geo. F. Staal on "Various Problems of a City Engineer." Attendance 70.

Panama.—May 28, 1916, Balboa Heights, C. Z. Election of officers for the coming year as follows—chairman, Richard H. Whitehead; vice-chairman, Earl J. Atkisson; secretary-treasurer, Carl W. Markham. Attendance 21.

Philadelphia.—May 8, 1916, Engineers Club. Paper: "Plant Design and Its Relation to Economy of Operation," by N. E. Funk. Attendance 90.

June 12, 1916, Kugler's Restaurant. Annual Dinner and business meeting. Brief addresses by President-elect H. W. Buck, Honorary Secretary R. W. Pope, Chairman J. H. Tracy, and Chairman-elect H. P. Liversidge. Election of officers for the coming year as follows—chairman, H. P. Liversidge; secretary-treasurer, William F. James; asst. secretary, Charles Penrose; managers, St. John Chilton, Benj. P. Foster and L. P. Costa. Attendance 85.

Pittsburgh.—June 13, 1916. Paper: "Recent Advances in the Human Side of Engineering," by Fred H. Rindge, Jr. Election of officers for the coming year as follows—chairman, G. C. Hecker; secretary-treasurer, F. E. Wynne. Attendance 42.

Rochester.—May 26, 1916, rooms of Rochester Engineering Society. Paper: "Theory and Practise of Electric Welding," by J. H. Bryan. Election of officers for the coming year as follows—chairman, O. W. Bodler; secretary-treasurer, Lucien Buck. Attendance 55.

San Francisco.—May 26, 1916, Engineers Club. Paper: "Laying of Power Cables across San Francisco Bay," by J. A. Koontz and L. P. Cornell. Attendance 65.

Seattle.—April 13, 1916, University of Washington. Visit to Annual Open House of the Engineering Department of the University of Washington.

May 16, 1916, University of Washington. Paper: "Testing for Defective Insulators on High-Tension Transmission Lines," by B. G. Flaherty. Brief report by Mr. Harisberger on the work of the Naval Consulting Board in the State of Washington. Attendance 20.

Spokane.—May 19, 1916, Silver Grill. Election of officers for the coming year as follows—chairman, D. F. Henderson; vice-chairman, C. A. Lund; secretary-treasurer, C. M. Fisher. Address by Mr. D. L. Huntington on "Ideal Qualifications of a Successful Engineer." Illustrated address on the Catskill Aqueduct by Mr. C. F. Ralston. Attendance 45.

Toledo.—June 7, 1916. Inspection trip to plant of Willys-Overland Company. Attendance 75.

Urbana.—May 4, 1916. Papers: (1) "Corona in Hydrogen and Rectification of Alternating Currents," by J. W. Davis and C. S. Breese; (2) "The Corona Discharge from Different Metals and Surfaces," by S. J. Crooker; (3) "Ionization Pressure and Corona Current," by E. H. Warner. Joint meeting with Electrical Engineering Society and the Physics Colloquium. Attendance 46.

June 6, 1916. Election of officers for the coming year as follows: chairman, I. W. Fisk; secretary-treasurer, L. V. James. Attendance 8.

Vancouver.—February 17, 1916, Board of Trade Rooms. Paper: "City of Kamloops Power Plant and Pumping System," by Mr. Dutcher. Joint meeting with local section of Canadian Society of Civil Engineers. Attendance 32.

Washington.—May 23, 1916, Cosmos Club. Election of officers for the coming year as follows—chairman, Arthur Dunlop; secretary, Louis G. Freeman. Paper: "The Electrification of the Chicago, Milwaukee and St. Paul Railway," by J. F. Layng. Attendance 118.

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PAST BRANCH MEETINGS

Armour Institute of Technology.—Election of officers for the coming year as follows—chairman, Ralph H. Earle; treasurer, William T. Watt; secretary, Harold A. Kleinman.

University of Cincinnati.—May 27, 1916. Annual Banquet. Election of officers for the coming year as follows—chairman, C. A. Powell; secretary-treasurer, H. V. McCormick. Attendance 54.

University of Colorado.—May 11, 1916, Engineering Building. Paper: "Interesting Facts and Figures in the Telephone Business", by C. L. Gomez. Election of officers for the coming year as follows—president, Charles C. Clymer; vice-president, Fred H. Wooley; secretary, Victor E. Leroy; treasurer, Allen E. Hinkle. Attendance 36.

Georgia School of Technology.—May 12, 1916. Educational moving pictures loaned by General Electric Company. Joint meeting with local branch of A. S. M. E. Attendance 70.

Kansas State Agricultural College.—May 19, 1916. Engineering amphitheater. Papers: (1) "High-Voltage Railway Practise"; (2) "Unipolar Generators"; (3) "New Electrical Developments." Attendance 25.

May 26, 1916. Address by Mr. W. R. Spangler on "Railway Signaling." Attendance 20.

Lafayette College. —May 22, 1916. Election of officers for the coming year as follows—president, Samuel McCoy Hunt; vice-president, Paul Herbert Taylor; secretary, Carl Theodore Mack. Papers: "Factory Lighting," by Edwin R. Baldridge; "High-Tension D-C. Railway Motors," by Alfred H. Drummond. Attendance 22.

Lehigh University.—May 18, 1916. Physical Laboratory. Papers: "The Electric Transmission," by C. W. Kingsley; "The Telephone Industry," by J. L. Montgomery. Election of officers for the coming year as follows—president, F. L. Magee; vice-president, H. E. McDowell; secretary, J. F. Wentz; treasurer, D. R. Brobst. Attendance 27.

University of Maine.—May 25, 1916. Illustrated lecture on "The Electrification of the Chicago, Milwaukee and St. Paul Railway," by W. D. Bearse. Election of officers for the coming year as follows—chairman, Fred P. Jones; vice-chairman, Francis McCabe; secretary, G. K. Wadlin; treasurer, R. J. Travers. Attendance 90.

University of Michigan.—May 30, 1916, Engineering Building. Illustrated address on "Storage Batteries," by Mr. Terry. Attendance 10.

June 7, 1916, Engineering Building. Address by Prof. J. E. Parker. Election of officers for the coming year as follows—chairman, A. N. Clarke; secretary, F. E. Richardson; treasurer, H. B. Bassett. Attendance 38.

University of Minnesota.—May 10, 1916. Election of officers for the coming year as follows—chairman, Jesse L. Thompson; secretary-treasurer, Donald P. Loye; executive committee, W. T. Ryan, William G. Dow and Irvin L. Boyum. Moving picture film, "Back to the Farm."

Ohio State University.—June 2, 1916, Ohio Union. Election of officers for the coming year as follows—chairman, H. D. Bender; vice-chairman, E. S. Gunn; secretary-treasurer, L. W. Birch. Attendance 29.

University of Oklahoma.—May 25, 1916, Engineering Building. Paper: "The Theory of Electrons," by C. J. Karcher. Election of officers for the coming year as follows—chairman, H. M. Richards; vice-chairman, C. M. Mackey; secretary, R. E. Heffner; treasurer, C. T. Hughes. Attendance 23.

Polytechnic Institute of Brooklyn.—May 19, 1916, Spicer Library. Illustrated lecture by Mr. Ferdinand Zogbaum on "The Operation of the New York, Westchester and Boston Railway." Attendance 24.

Rensselaer Polytechnic Institute.—May 5, 1916, Sage Laboratory. Illustrated address by Mr. Walter D'Arcy

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Ryan on "The Illumination of the Panama-Pacific International Exposition." Attendance 176.

May 23, 1916, Sage Laboratory. Election of officers for the coming year as follows—chairman, W. J. Williams; secretary, W. R. Townsend, Jr. Attendance 32.

Stanford University.—May 4, 1916. Annual Banquet; brief addresses by Professors H. J. Ryan, J. C. Clark, W. F. Durand, C. D. Marx and Mr. W. A. Hillebrand. Attendance 26.

May 9, 1916. Election of officers for the coming year as follows—chairman, H. J. Rathbun; secretary, J. A. Shepard; treasurer, M. J. Cody. Attendance 18.

Syracuse University.—May 11, 1916. Paper: "Storage Batteries," by E. J. Gibbons. Attendance 12.

May 18, 1916. Paper: "Automobile Lighting and Starting Systems," by F. B. Avery. Attendance 12.

May 25, 1916. Paper: "Automobile Ignition," by C. W. Minard. Attendance 10.

Throop College of Technology.—May 8, 1916, Pasadena Hall. Illustrated lecture on "The Development and Growth of the General Electric Company," by A. L. Rohrer. Attendance 136.

Washington University.—May 31, 1916. Election of officers for the coming year as follows—chairman, Chas. A. Lieber; vice-chairman, Leslie M. Barre; secretary-treasurer, R. W. Macdonald. Attendance 11.

University of Washington.—May 25, 1916, Forestry Building. Election of officers for the coming year as follows—chairman, A. Kalin; secretary, J. R. Himmelsbach. Papers: (1) "Efficiency Test on Electric Plant," by E. E. McKeen; (2) "Radio Sets on Board Ships," by F. M. Ryan; (3) "Singing Arcs", by A. A. Edson. Attendance 20.

West Virginia University.—Election of officers as follows—chairman, C. R. Huffman; secretary, H. S. McLaughlin.

Worcester Polytechnic Institute.—May 19, 1916, Electrical Engineering Building. Paper: "The Design and Construction of a 750-Mile Artificial Transmission Line," by D. M. Russell. Election of officers for the ensuing year as follows—president, C. W. Kennedy; secretary-treasurer, J. A. Blair. Attendance 19.

PERSONAL

MR. GUIDO SEMENZA, of Milan, Italy, President of the Associazione Elettrotecnica Italiana, President of the Italian Committee of the International Electrotechnical Commission, and Local Honorary Secretary of the A. I. E. E. for Italy, has recently been promoted by the King of Italy from the rank of Cavaliere ("knight") to that of Commendatore ("officer") of the knighthood of the "Corona d'Italia."

MR. HOWARD S. WILSON, who has been for the past nine years connected with the New England Engineering Company, of Waterbury, Conn., as engineer, and manager of the power equipment department, has resigned from that position, but will continue to live in Waterbury. Mr. Wilson was connected with the General Electric Company, and the Submarine Signal Company of Boston, before taking up his work for the New England Engineering Company.

MR. EDMUNE J. HENKHE, who was connected for over eight years with the Russian and British Westinghouse Companies, and has been during the last five years assistant to the president of the International Textbook Company of Scranton, Pa., severed his connection with the latter concern on June 1, and is at present with the Thomson Electric Welding Company, of Lynn, Mass., in the capacity of assistant general manager in charge of the engineering and sales departments.

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MR. P. W. SOTHMAN announces the formation of a new organization known as the Sothman Construction Corporation, with headquarters at 40 Exchange Place, New York City. The corporation is organized to carry on general electrical construction work, such as erecting transmission lines, installation of submarine cables, construction of underground distributing systems, power plants, lighting plants, electric railway systems, etc. The organization is made up of men who have had wide experience in their respective lines.

OBITUARY

SILVANUS PHILLIPS THOMPSON, Hon. Mem. A. I. E. E., past-president of the Institution of Electrical Engineers, noted physicist and electrical engineer and celebrated as a teacher and writer on electricity and magnetism, died in London on June 13, 1916. He was born at York, England, June 19, 1851, and was educated at the Friends' School in that city, and the Founders' College. In 1869 he was graduated from London University with the degree of B. A. He then took up the study of chemistry and physics at the Royal School of Mines, and spent some time in study at Heidelberg and other foreign universities. Mr. Thompson was graduated from the University of London in 1875 with the degree of B. S. In 1878 he received the degree of doctor of science from the same university, and in that year was appointed professor of experimental physics in Bristol University College. Here he began a series of investigations covering a wide range of problems in physics and electricity. Professor Thompson applied the magnetic figures formed with iron filings to the explanation of electrodynamic relations and the action of the dynamo-electric machine. He applied Clerk Maxwell's electromagnetic theory of light to the explanation of the effect of tourmaline crystals on polarized light, and constructed electro-optic models of these crystals out of iron wire and glass. Professor Thompson's Cantor lectures in 1883 on the construction, theory and mode of operation of dynamoelectric machines established his reputation as an authority on the subject. In 1885 he was elected to fill the chair of physics at the City and Guilds Technical College, Finsbury, London, where he was also principal. Professor Thompson has always been famous as a writer on electrical subjects whose work was marked by unusual lucidity, directness and literary style. He also made many contributions to the history of science and philosophy. His "Elementary Lessons in Electricity and Magnetism" has been one of the most widely read treatises on the subject, and has been translated into many languages. Among his other well-known works are "Dynamo-electric Machinery," "The Electromagnet," "Polyphase Electric Currents and Motors," "Michael Faraday—His Life and Work," "Light, Visible and Invisible," and the "Life of Lord Kelvin." Professor Thompson was a member of many scientific and learned bodies, and had been honored by election to the presidency of many of them. He was first elected to membership in the American Institute of Electrical Engineers on October 27, 1897, and was elected an Honorary Member on March 13, 1914.

The Board of Directors of the Institute adopted the following resolutions on June 28, 1916:

WHEREAS, the sudden death on June 13, 1916, of our Honorary Member, Silvanus Phillips Thompson, removes from the scientific world and the electrical profession one of their most distinguished ornaments; and

WHEREAS, Dr. Thompson, in addition to his many notable achievements as a scholar, educator, scientist and inventor, did brilliant service in giving to the world the first systematic text-books on modern electrical science, and some of its important technical applications; be it

RESOLVED, that the members of the Board of Directors of the American Institute of Electrical Engineers hereby record their deep sorrow at the loss to the world of an untiring worker in its higher interests, of an accomplished scholar and an inspiring personality; and be it

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FURTHER RESOLVED, that a copy of these resolutions be forwarded to the members of his family, to whom profound sympathy is extended in their bereavement.

RECOMMENDED FOR TRANSFER, JUNE 15, 1916

The Board of Examiners, at its regular monthly meeting on June 15, 1916, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

TO THE GRADE OF FELLOW

BURTON, PAUL GIBSON, Engineer, Chesapeake and Potomac Tel. Co. and Associated Cos., Baltimore, Md.

MITCHELL, JAMES, Alabama Power Co., New York, N. Y.

TO THE GRADE OF MEMBER

BATCHELDER, C. E., Engineer, General Electric Co., Buenos Aires, A. R.

BLACKALL, FREDERICK S., Vice-President and General Manager, Taft-Peirce Mfg. Co., New York, N. Y.

DATE, WILLIAM EDSON, Engineer, Cutler-Hammer Mfg. Co., New York, N. Y.

FRANCISCO, FERRIS LEROY, Consulting Engineer, New York, N. Y.

HERZ, ALFRED, Public Service Co. of Northern Illinois, Chicago, Ill.

LIPSCOMB, GASTON JOEL, Engineer, W. R. Grace & Co., Iquiqui, Chile.

LYON, JESSE D., Consulting Engineer, Cincinnati, O.

MCCARTY, FRANCIS ALEXANDER, Consulting Electrical Engineer, Melbourne, Australia.

SHEPPARD, H. S., Assistant Professor of Electrical Engineering, University of Michigan, Ann Arbor, Mich.

WALLOWER, EDGAR Z., General Manager, Lockport Light, Heat and Power Co., Lockport, N. Y.

WESTBURG, PAUL A., President, Badt-Westburg Electric Co., Chicago, Ill.

FELLOW ELECTED JUNE 28, 1916

GORDON, WILLIAM GORDON, Transportation Engineer, Canadian General Electric Co., Ltd., Toronto, Ontario.

TRANSFERRED TO THE GRADE OF MEMBER JUNE 28, 1916

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on June 28, 1916.

CHANDLER, WILLIAM A., Electrical Engineer, H. C. Frick Coke Co., Bunsen Coal Co., Scottdale, Pa.

HEDGES, GEORGE L., Engineer, Kelman Electric & Mfg. Co., Los Angeles, Cal.

HOEN, W. M., General Engineer, Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

PIGOTT, R. J. S., Power Supt., Remington Arms and Ammunition Co., Bridgeport, Conn.

SESSIONS, FRANK L., Consulting Engineer, Cleveland, O.

SHEPHERD, CLAUDE H., Electrical Engineer in charge, Commissioners of Lincoln Park, Chicago, Ill.

SMITH, E. W. P., City Electrician, Cleveland, O.

WALLER, ALFRED E., Production Manager, Ward Leonard Electric Co., Bronxville, N. Y.

MEMBERS ELECTED JUNE 28, 1916

HILL, WILLIAM WELCH, Professor of Electrical Engineering, Alabama Polytechnic Institute, Auburn, Ala.

HOLDING, HERBERT H., General Power Representative, Public Service Electric Co., Newark; res., 132 N. Grove St., East Orange, N. J.

KIRSTEN, KURT FRIEDRICH JOHANNES, Assistant Professor of Electrical Engineering, University of Washington, Seattle, Wash.

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ASSOCIATES ELECTED JUNE 28, 1916

ANDERSON, STEWART WISE, Adjunct Professor, Dept. of Physics & Electrical Engineering, Virginia Military Institute, Lexington, Va.

ARGO, MALCOLM MARION, Chief Electrician, Alabama Fuel and Iron Co., Acmar, Ala.

ARMSTRONG, F. W., Electrical Engineer, British Army; res., 7 Fernshaw Rd., Fulham Rd., S. W., London, Eng.

ARTHUR, MARCUS WILSON, Salesman and Engineer, Westinghouse Electric & Mfg. Co., 1107 Traction Bldg., Cincinnati, O.

ATWOOD, JAMES ANDREWS, Electrical Contractor and Engineer, 127 N. Jefferson St., Dayton, Ohio.

BENNETT, AUDLEY CARLISLE, Inspector, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., 908 Wood St., Wilkinsburg, Pa.

BILLINGS, WARREN C., Supt., Power & Light Dept., Cumberland County Power & Light Co., Portland, Maine.

*BOULT, JAMES BEN, Draftsman and Engineer, Union Carbide Co.; res., 714 Spruce St. E., Sault Ste. Marie, Mich.

BREHM, CLYDE G., Chief Electrician, Oliver & Snyder Steel Co., Oliver; res., 104 Millview St., Uniontown, Pa.

BROWN, GEORGE J., Electrical Inspector, Office of Provincial Electrical Engineer, Province of Manitoba, New Parliament Bldgs., Winnipeg, Man.

BROWN, RALPH E., Electrical Expert, General Electric Co.; res., 1441 W. 68th St., Chicago, Ill.

BULLEY, GEORGE WILSHEAR, President, Mercury Manufacturing Co., 4110 S. Halsted St., Chicago, Ill.

BURGESS, HERBERT RODNEY, Territorial Manager, National Carbon Co., Cleveland, Ohio.

BURNETT, JAMES HENRY, Rotary Tender, New York Railways Co., New York; res., 439 Ocean View Ave., Woodhaven, L. I., N. Y.

CHAPMAN, ARTHUR GARNER, Electrical Engineer, American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

COBB, FRANCIS CUTTER, Electrical Engineering Assistant, Public Service Electric Co., Newark, N. J.

COLLOPY, JOSEPH PATRICK, Electrician, Great Western Sugar Co., Scottsbluff, Nebr.

COOK, WILLIAM S., Engineer, Canadian Porcelain Co., Hamilton, Canada.

CROSBY, LEMUEL STEPHENS, Transmission and Inductive Disturbances, Division Plant Office, American Tel. & Tel. Co., 1422 Hart Bldg., Atlanta, Ga.

DANKO, JOSEPH PETER, Instructor of Gyro Compass, Sperry Gyroscope Co., Brooklyn, N. Y.; res., 173 Wainwright St., Newark, N. J.

*DAVISON, VERGIL ALVIN, Foreign Sales Dept., Western Electric Co., New York, N. Y.; res., 366 Van Houten Ave., Passaic, N. J.

DICKEY, WILLIAM HAMILTON, Sales Dept., National Carbon Co., Cleveland, O.

DOYLE, ALFRED JOSEPH, Junior Electrical Engineer, Public Service Commission, 1st District, New York; res., 242 Monroe St., Brooklyn, N. Y.

DRAKE, ALBERT W., Assistant General Superintendent of Plant, American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

FUCHS, JOHN OSCAR, Assistant Engineer, Central Hudson Gas & Electric Co., Poughkeepsie, N. Y.

GODDARD, RALPH WILLIS, Professor of Electrical Engineering, New Mexico College of Agriculture and Mechanic Arts, State College, N. M.

*GORDON, CLAUDE PHILIP, Electrician, Port of Seattle; res., 5025 36th Ave. S. W., Seattle, Wash.

GORMAN, HORACE PFOUTS, Student, New York Electrical School, 39 W. 17th St.. New York, N. Y.

GRAY, CHARLES HARRISON, Master Mechanic and Chief Electrician, Fort Pitt Steel Casting Co.; res., 1213 S. Park St., McKeesport, Pa.

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GRAYSON, ALFRED CLARK, Electrical Engineering Assistant, Public Service Electric Co., P. S. Building, Newark, N. J.

HALEY, HARRY STEELE, Member of firm, Leland and Haley, 434 Holbrook Building, San Francisco, Cal.

HARBOLD, CLARENCE ELISHA, Chief Electrician, Aurora Consolidated Mines Co., Aurora, Nev.

HERRICK, DEWITT CLINTON, In Charge of Research Section, Engineering Dept., National Lamp Works of G. E. Co., Nela Park, Cleveland, O.

HINES, BEDFORD FORREST, Signal Engineer, N. O. & N. E. R. R., A. & V. Ry., and V. S. & P. Ry.; res., 305 2nd Ave., Hattiesburg, Miss.

HOVELSON, HENRY, Superintendent of Electrical and Mechanical Construction, C. L. Pillsbury Co., 805 Metropolitan Life Bldg., Minneapolis, Minn.

HOWK, CLARENCE LEROY, Telephone Engineer, Western Electric Co., 463 West St., New York, N. Y.

JENNEY, LEE R., Division Superintendent of Plant, American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

JOHNSON, HERBERT BELDEN, Chief Electrician, Southern Cotton Oil Co.; res., 1739 St. Charles Ave., New Orleans, La.

JONES, ARCHER KNIGHT, Electrician, Compania de Luz y Fuerza Electrica, San Ramon, Costa Rica, C. A.

KEYES, JOHN JUDSON, Research Division, Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., 818 South Ave., Wilkinsburg, Pa.

KIMBALL, AUSTIN L., Construction Dept., Otis Elevator Co., 1202 4th Ave., Seattle, Wash.

KUEHN, NORMAN L., Electrical Engineer, Commerce St. Power Plant, Milwaukee Electric Railway & Light Co.; res., 3703 Galena St., Milwaukee, Wis.

LEGIER, EDWARD WILTON, Student Engineer, General Electric Co.; res., 121 N. Common St., Lynn, Mass.

*LINDSAY, HARRY BERNARD, Instructor, Electrical Engineering, Post Graduate Dept., U. S. Naval Academy, Annapolis, Md.

LUFT, O. L., Substation Operator, Union Electric Light & Power Co.; res., 3129a Gravois Ave., St. Louis, Mo.

MACKAY, WILLIAM JAMES, Switchboardman, Pacific Tel. & Tel. Co.; res., 3053 28th Avenue West, Seattle, Wash.

MARKLEY, FRANK R., Electrical Sales Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh; res., 835 Rebecca Ave., Wilkinsburg, Pa.

MCCARTY, ROY ANDERSON, Engineering Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh; res., 607 Whitney Ave., Wilkinsburg, Pa.

MCWILLIAMS, MICHAEL, Engineer, Waipori Falls Power Station, Waipori Falls, Dunedin, N. Z.

MEAD, CHARLES ALVAN, Clerk and Meter Tester, Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., 751 Franklin Ave., Wilkinsburg, Pa.

MILLER, THEODORE G., Division Superintendent of Plant, American Telephone & Telegraph Co., 212 West Washington St., Chicago, Ill.

MOREN, WILHELM HUGO, Electrical Engineer, Allmanna Svenska Elektriska A/B; res., Gustafsgatan 14, Vasteras, Sweden.

MURRAY, J. B., Assistant to Vice-President & General Manager, Brooklyn Edison Co., 360 Pearl St., Brooklyn, N. Y.

*OBER, DEAN C., Electrical Engineering, Cleveland Electric Illuminating Co.; res., 1439 Lakeview Rd., Cleveland, O.

O'HARA, DAVID G., (Electrical) Instructor, Vocational School for Boys; res., 2429 Valentine Ave., New York, N. Y.

PAINE, NATHAN DEANE, Foreman Electrician, Price Bros. & Co. Ltd., Staff House, Kenogami, P. Q., Canada.

RICKARD, EVERETT BERNON, Electrical Engineer, Vandalia R. R. Co., Terre Haute, Ind.

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RICKETTS, FORREST EUGENE, Superintendent, Electric Stations, Consolidated Gas, Electric Light & Power Co. of Baltimore, 100 W. Lexington St., Baltimore, Md.

ROMANOVSKY, CHARLES, Electrical Engineer, Switchboard Dept., General Electric Co.; res., 136 Third Ave., Schenectady, N. Y.

SAENZ DE CALAHORRA, AMADEO, Assistant Manager, Foreign Business, J. A. Fay & Egan Co.; res., 146 W. 65th St., New York, N. Y.

SMITH, E. A., Motive Power Dept., Interborough Rapid Transit Co., 600 W. 59th St., New York, N. Y.

SOULE, HERBERT CLINTON, General Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh; res., 1222 Mill St., Wilkinsburg, Pa.

SPANGENBERG, OTTOMAR CARL, Electrician, Mt. Sinai Hospital; res., 1102 Washington Ave., New York, N. Y.

SPARLING, ERIC CARLETON, Technical Assistant, Sperry Gyroscope Co., 15 Victoria St., London S. W., England.

SPASOFF, JOHN, Substation Operator, Pacific Gas & Electric Co., San Rafael, Cal.

STEVENSON, FREDERIC AUGUSTUS, General Superintendent of Plant, Long Distance Lines Dept., American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

STIMSON, HENRY BOGUE, Traffic Engineering, American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

*STONEMAN, EDWIN CURTIS R., Power Inspector, Bell Telephone Co. of Canada; res., Central Y. M. C. A., Drummond St., Montreal, Quebec.

*STUCKEMAN, WILLIAM FRANKLIN, Salesman and Service Manager, Wagner Electric Mfg. Co.; res., 22 Ruth St., Pittsburgh, Pa.

STURGE, JOHN HOWARD, Assistant Division Superintendent, Public Service Electric Co., 225 N. Warren St., Trenton, N. J.

TELFER, LORENZO HENRY, Electrical Superintendent, Great Northern Railway Co., Wellington, Wash.

THISTLEWHITE, ROBERT, Instructor, New York Electrical School, New York, N. Y.; res., Whatnong Terrace, Morris Plains, N. J.

THORNTON, FREDERICK LEANDER, Auditor, Kansas City Light & Power Co., 1500 Grand Ave., Kansas City, Mo.

TORRANCE, JAMES JEWETT, Electrical Draughstman, Interborough Rapid Transit Co., 600 W. 59th St., New York, N. Y.

TORREY, WRAY A., Manager, Avoca Electric Light & Power Co., Avoca, Iowa.

TURNER, EDGAR P., Engineer in Charge, Christchurch Tramway Board, Christchurch, New Zealand.

TURNOCK, HARRY C., President and General Manager, Electric Construction & Sales Co.; res., 10703 Ashbury Ave., N. E., Cleveland, O.

ULLOA, ANGEL OSCAR, Chief Electrician, Esperanza Mining Co., El Oro, Mexico, Mex.

ULRICH, BENJAMIN HARRISON, Power Engineer, Public Service Electric Co., Newark; res., 176 N. 17th St., East Orange, N. J.

*WELLER, ERNEST, Engineering Dept., New York Telephone Co.; res., 318 W. 57th St., New York, N. Y.

WHITING, L. R., Salesman, Westinghouse Electric & Mfg. Co., 1205 Dime Bank Building, Detroit, Mich.

WILLIAMS, HOWARD KNOWLTON, Superintendent Underground Construction, Cleveland Electric Illuminating Co., 308 Illuminating Bldg., Cleveland, O.

WILSON, JOHN MARION, Engineer, Engineering Dept., Western Electric Co.; res., 371 Wadsworth Ave., New York.

WOOLL, JOHN HASTINGS, Construction Engineer, Sierra and San Francisco Power Co.; res., 1315 Jackson St., San Francisco, Cal.

WURTS, THOMAS CHILDS, Railway Engineering Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh; res., 1164 Shady Ave., Pittsburgh, Pa.

Total 85.

*Former enrolled Students.

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APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before July 31, 1916.

Anderson, C. E., Ancon, C. Z.
Apeseche, R. F., Buenos Aires, A. R.
Armstrong, E. R., City Point, Va.
Bach, W. K., Brooklyn, N. Y.
Bechlem, A. W., Gatun, C. Z.
Bollinger, N. M., Pittsburgh, Pa.
Busselle, E. T. (Member), Salem, Ore,
Churchill, B. F., Denver, Colo.
Clokey, A. A., New York, N. Y.
Cooke, R. F., Lewiston, Cal.
Crewson, G. G., Perth Amboy, N. J.
Disbrow, G. G., Lynchburg, Va.
Espenschied, F. F., Toronto, Ont.
Fairbank, P. W., New Britain, Conn.
Fantozzi, C. T. J., Chicago, Ill.
Fink, H., Jr., San Antonio, Tex.
Flanders, L. H. (Member), Philadelphia, Pa.
Forster, T. F., Pittsfield, Mass.
Gailunas, J. P., Detroit, Mich.
Gardner, L. H. (Member), Minneapolis, Minn.
Glienke, H. E., Chicago, Ill.
Gordon, M. W., Johnstown, N. Y.
Grigsby, B. J., London, England.
Gustafson, R. V., Chicago, Ill.
Hale, G. R. S, Boston, Mass.
Hammond, H. H., Boston, Mass.
Hartman, L. J., Newark, N. J.
Hill, F. W. L., New York, N. Y.
Jacobs, A.M.(Member),New York,N.Y.
Johnson, C. A., El Paso, Tex.
Jones, H. S., San Francisco, Cal.
Kerrigan, A. J., Lowell, Mass.
Ketchum, G. C., Chicago, Ill.
Laurenson, J. S., Ipswich, Australia.
Levvy, A., Winnipeg, Man.
Martin, H., Jr., New York, N. Y.
Matthews, C. T., Kennebec, N. C.
Meyer, H. W., Minneapolis, Minn.
Miser, W. B., Jacksonville, Ill.
Moffatt, D. H., Balboa, C. Z.
McDonald, D. W., Pedro Miguel, C. Z.
Olmsted, C. S., New York, N. Y.
Ostermann, G. R., Woodland, Cal.
Owen, C. S., Cleveland, O.
Owen, N. J., Pedro Miguel, C. Z.
Phillips-Watts, J., Trail, B. C.
Plowman, A. S., Broken Hill, N. S. W.
Reeder, C. H. (Member), Chicago, Ill.
Richardson, A. N., Kansas City, Mo.
Ross, E. W., Jr., Eddystone, Pa.
Shedd, M. E., Norwich, Conn.
Stanley, F. A. (Member), New York, N. Y.
Stokes, S., Webster Groves, Mo.
Van Bergen, K. B., St. Paul, Minn.
Wells, A. S., Lowell, Mass.
West, C. O., Los Angeles, Cal.
Woodruff, W. W., Wilmington, Del.
Wygod-Wygodsky, H., New York, N.Y.
Yamato, S., Kobe, Japan.
Total 59.

STUDENTS ENROLLED JUNE 28, 1916

8187 Oaks, E. L., Stanford University.
8188 Tindall, V. L., Stanford Univ.
8189 Kinnear, L. S., Stanford Univ.
8190 Shriver, H. D., Stanford Univ.
8191 Parker, H. C., Stanford Univ.
8192 Schlader, E. H., Univ. of Ill.
8193 Heuser, J. U., Univ. of Wis.
8194 Kaupp, C. O., Penn. State Coll.
8195 Foster, N. M., Univ. of Kansas.
8196 DeCou, R. C., Univ. of Nebr.
8197 Clark, E. L., Mass. Inst. Tech.
8198 Hall, W., Univ. of Nebraska.
8199 deSouza,J.T.,Ohio NorthernUniv.
8200 Petterson, A. A., Wentworth Inst.
8201 Ladenburg,C.,Montana StateColl.
8202 Hill, H. P., Armour Inst. Tech.
8203 Campbell, D. A., Univ. of Colo.
8204 Todd, G., Stevens Inst. Tech.
8205 Perry, G.D., Rensselear Poly.Inst.
8206 Enzler, L. J., Armour Inst. Tech.
8207 Fox, L. R., Lafayette College.
8208 Sly, J. A., Wash. State Coll.
8209 Reichel, A. E., Wash State Coll.
8210 Huntington, R., Wash. State Coll.

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8211 Bjorkman, C., Worcester Poly. Inst.
8212 Smith, R. L., Univ. of Penna.
8213 Loye, D. P., Univ. of Minn.
8214 Graw, W. S., Carnegie Inst. Tech.
8215 Gunts, R. F., Mass. Inst. Tech.
8216 Heffner, R. J., Univ. of Calif.
8217 Kramer, R. S., Lafayette College.
8218 Cooper, D. W., Univ. of Illinois.
8219 Rust, L. J., Univ. of Illinois.
8220 Kirkpatrick, T. P., Georgia School of Technology.
8221 Woodbury, R. F., Wentworth Inst.
8222 Jobim, A. deC., Rensselaer Poly Inst.
8223 Craighead, R. L., Worcester Poly. Inst.
8224 Owler, D. S., Mass. Inst. Tech.
8225 Olsen, R. B., Pratt Institute.
8226 Dickey, D. A., Ohio State Univ.
8227 Hancock, G.E., Univ. of Nebraska.
8228 Barbour, M.A., Univ. of Michigan.
8229 Finley, A. M., Univ. of Missouri.
8230 Murphy, J.E., Worcester Poly. Inst.
8231 Wright, W. F., Clemson College.
8232 Bakke, T. T., Univ. of N. D.
8233 Ettele, C., Carnegie Inst Tech.
8234 Abbett, H. W., Purdue Univ.
8235 Mitten, G. R., Purdue Univ.
8236 Ivy, C. N., Purdue University.
8237 McKinley, V. L., Purdue Univ.
8238 Kline, K., Purdue University.
8239 Stout, A. V., Purdue Univ.
8240 Bedig, H.G., Worcester Poly. Inst.
8241 Ekdahl, E. A., Mass. Inst Tech.
8242 Vendig, M. C., Univ. of Penna.
8243 Delaney, T.J., Worcester Poly. Inst.
8244 Allison, J. L., Univ. of Michigan.
8245 Smith, C. W., Univ. of Michigan.
8246 Gowing, M. R., Ohio State Univ.
8247 Orr, R. P., Univ. of Wisconsin.
8248 Harvey, A. A., Wentworth Inst.
8249 Abbott, E. S., Univ. of Wis.
8250 Schmitz, N. J., Univ. of Wis.
8251 Mueller, F. P. G., Univ. of Wis.
8252 Niesse, J. L., Purdue Univ.
8253 Strand, L. M., Univ. of Wis.
8254 Chesnut, R. W., Harvard Univ.
8255 Jones, A. P., Ga. Sch. of Tech.
8256 Cope, K. H., Univ. of Wis.
8257 Olofson, O. H., N. Y. Elec. Sch.
8258 Paxson, O. H., Univ. of Penna.
8259 Knotts, C. L., Penna State Coll.
8260 Gautert, R. M., Univ. of Penna.
8261 Peterson E. G., Carnegie Inst. of Technology.
8262 Long, H. M., Penna. State Coll.
8263 Burkhart, P. H., Univ. of Ill.
8264 Hughes, M. C., Univ. of Ill.
8265 Offerbaus, W. R., Toronto Univ.
8266 Swartley, S. N., Univ. of Penna.
Total 80.

ACCESSIONS TO LIBRARY

This list includes books on electrical subjects only, which have been added to the library of the A. I. E. E. and the U. E. S. during the past month, not including periodicals and other exchanges.

Electrical Patents (Collection of) (Gift of Robert Allen.)

Gas, Electric and Street Railway Association of Oklahoma. Transactions of Fourth Annual Convention, 1915. Norman, 1915. (Gift of Association.)

International Catalog of Scientific Literature. 13th Annual Issue. C—physics. London, 1915. (Gift Edward D. Adams.)

Logaritmos, antilogaritmos, senos, kosenos, tanjentes. Santiago de Chile, 1911. (Gift of A. E. Salazar.)

Massachusetts Gas and Electric Light Commissioners. Annual Report. 31st, 1915. Boston, 1916. (Gift of Gas and Electric Light Commissioners.)

New York State. Public Service Commission, Second District. Annual Report, 1915, volume I. Albany, 1916. (Gift of Commission.)

Statistical Report of Electric Undertakings in Japan, 1913, 1914. (Gift of Japan. General of Electric Exploitations, Department of Communications.)

Telephone Rates in Detroit. An investigation of the proposed advance in rates of the Michigan State Telephone Company in the Detroit District. By Edward P. Burch. Detroit, 1916. (Gift of author.)

UNITED ENGINEERING SOCIETY

Centrifugal Fans. By J. H. Kinealy. New York, 1905. (Purchase.)

Electrical Conductivity and Ionization constants of Organic Compounds. By Heyward Scudder. London, 1914. (Purchase.)

Electrical Engineering First Course. By E. J. Berg and W. L. Upson. New York, 1916. (Purchase.)

Electron Theory, The. Ed. 3. By E. E. Fournier. London, 1909. (Purchase).

Handbook of Formulas and Tables for Engineers. Compiled by Clarence A. Peirce & W. B. Carver. New York, 1914. (Purchase.)

Handbuch der Radiologie. By Erich Marx. Band III. Leipzig, 1916. (Purchase.)

McGraw Central Station List, April 1916. New York, 1916. (Purchase.)

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Overhead Conductor Electric Railway Co. Description of J. R. Finney system. Pittsburgh, 1887. (Purchase.)

Photo-Electricity. The Liberation of Electrons by Light. By H. S. Allen. London, 1913. (Purchase.)

Relativity and the Electron Theory. By E. Cunningham. London, 1915. (Purchase.)

Results of Observations made at the United States Coast and Geodetic Survey magnetic observatory at Sitka, Alaska, 1913 and 1914. Washington, 1916. (Purchase).

Results of Observations made at the United States Coast and Geodetic Survey magnetic observatory near Tucson, Arizona, 1913 and 1914. Washington, 1916. (Purchase.)

Study and Review of the Problem of Passenger Transportation in Philadelphia by a Unified System of Lines. March 29, 1916. (Gift of Department of City Transit.)

Value for Rate Making. By Henry Floy. New York, 1916. (Purchase.)

GIFT OF CARL HERING

L'Alternateur, systeme Boucherot, de 1000 HP exposé par la Maison Breguet et accouplé avec la machine a vapeur Delaunay-Belleville.

Armature of Elphinstone & Vincent Machine (Drawings)

Brown Single Phase Induction Motor Curves. 1900. (Blue print.)

Discussion of series dynamo-electric machines. By Carl Kinsley, 1898.

Starting Gear of an Induction Motor. 1900. (Drawing.)

Sur le Calcul de Machines electriques. Ateliers de Construction Oerlikon. 1900.

System of Control for Electric Motors. By Ward Leonard.

Theory of Commutation. By C. C. Hawkins.

Unipolar Dynamo. 1891. (Description and blue print.)

Die Vorausberechnung der Dynamomaschinen.

EMPLOYMENT DEPARTMENT

Note: Under this heading brief announcements (not more than fifty words in length) of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months: during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

VACANCIES

V-145. Assistant in Electrical Engineering in a Western university. Duties include teaching and laboratory instruction. Teaching or testing experience desirable. Salary $800 for nine months, dating from September 15.

MEN AVAILABLE

513. Sales Engineer, Manager or Superintendent. Age 35; fifteen years' experience in design, manufacture and sale of electrical machinery; a capable executive and organizer, thoroughly familiar with modern shop practise and well acquainted with trade, desires to communicate with manufacturer wishing services of a live and up-to-date executive. Mem. A. I. E. E. Assoc. Mem. A. S. M. E.

514. Electrical and Mechanical Engineer, twenty years' practical experience large power plant design and construction, mechanical and electrical, high- and low-tension; specifications; correspondence; estimating; supervising; inspecting; handling men. Reliable, energetic; married. Desires broader field or connection with manufacturing or automobile business. Preferably New York, but would consider other locations.

515. Who wants me? Successful salesman, technically trained, seeks connection with manufacturer, domestic or export service. Qualified for executive, manufacturing or administrative position. Single, will go anywhere. Secure this high-grade man now.

516. Electrical Engineer, technical graduate, age 28, desires to become connected with electric railway or engineering company. Has had five years experience in the electric railway field—two in testing department, three in engineering office and operation. Employed at present; single, energetic, capable.

517. Electrical Engineer, with fifteen years' practical experience installing light and power systems, is open for

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engagement as superintendent or engineer in charge. Married; age 35. At present in charge of suction gas electric lighting plant; over three years. Has good theoretical training.

518. Successful Electrical Engineer. Twelve years' experience as designing engineer with leading manufacturing concerns. Author of several original magazine publications; desires teaching position with Eastern university.

519. Electrical Engineer, age 25, graduate (1915) Univ. of Illinois. Desires purely engineering employment, but would consider teaching engineering subjects.

520. Graduate Engineer and Electrician, 29, married. Eight years' experience in operation, maintenance and construction of steam plants and substations in U. S. A. and abroad, desires to assist in construction of power plant with a view to taking charge of same upon completion. Now employed on Pacific Coast, but would go East.

521. Assoc. A. I. E. E. desires position with small ice and electric plant, institution or farm. Eighteen years' experience with steam, hydro and gasoline engine electric plants, also ice plants, pumping plants, concrete construction and some Diesel engine experience. Familiar with G. E., Westinghouse, Allis-Chalmers and Crocker-Wheeler apparatus. Age 27; can accept on short notice; willing to go anywhere.

522. Electrical and Mechanical Graduate. One year Westinghouse test experience; one year chief electrician; four years' experience in electric traction as assistant master mechanic and engineer of rolling stock. Energetic, robust, steady, original, strong character, age 29, single. Power plant, electric railway or industrial engineering position desired. Experienced in handling and employing men with best results.

523. Electrical Maintenance Engineer. Fifteen years' experience in large industrial plants. Can leave on thirty days' notice. Salary desired $175 per month.

524. Telephone Electrical Engineer, 31. Nine years' experience in different parts of the world in engineering, construction, operation and management of all kinds of telephone plants. Efficiency guaranteed. Speaks fluently English, Swedish, Spanish, German, and French. At present chief engineer of large company, but desires change.

525. Electrical Engineer, age 33, desires to make connection with manufacturing, engineering or contracting concern. Eleven years' experience with consulting electrical engineers in New York City.

526. Electrical Engineer, age 22, 1916 Columbia graduate, desires position, preferably with consulting or construction engineers and contractors, but will consider anything. Initial salary is secondary to permanence and future prospects of the position.

527. Graduate New York Electrical School; age 24; now employed, desires position with construction engineer, industrial or railroad company. Four years' experience as wireman and in general repair work.

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(Term expires July 31, 1916.)

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(Term expires July 31, 1916.)
C. O. MAILLOUX.

(Term expires July 31, 1917.)
P. M. LINCOLN.

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(Term expires July 31, 1916.)
F. S. HUNTING.
N. W. STORER.
FARLEY OSGOOD.

(Term expires July 31, 1917.)
C. A. ADAMS.
J. FRANKLIN STEVENS.
WILLIAM McCLELLAN.

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(Term expires July 31, 1916.)
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B. A. BEHREND.
P. JUNKERSFELD.
L. T. ROBINSON.

(Term expires July 31, 1917.)
FREDERICK BEDELL.)
BANCROFT GHERARDI.
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(Term expires July 31, 1918.)
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*FRANKLIN L. POPE, 1886-7.
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EDWARD WESTON, 1888-9.
ELIHU THOMSON, 1889-90.
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-2.
FRANK JULIAN SPRAGUE, 1892-3.
*EDWIN J. HOUSTON, 1893-4-5
*LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
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CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4.
JOHN W. LIEB, 1904-5.
SCHUYLER SKAATS WHEELER, 1905-6.
SAMUEL SHELDON, 1906-7
HENRY G. STOTT, 1907-8.
LOUIS A. FERGUSON, 1908-09.
LEWIS B. STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.
RALPH D. MERSHON, 1912-13.
C. O. MAILLOUX, 1913-14.
PAUL M. LINCOLN, 1914-15.

*Deceased.

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STANDING COMMITTEES

Revised to July 1, 1916

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C. A. Adams, William McClellan,
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A. S. McAllister, J. Franklin Stevens.

FINANCE COMMITTEE.

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1326 Chestnut Street, Philadelphia, Pa.
Bancroft Gherardi, Farley Osgood.

LIBRARY COMMITTEE.

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General Electric Company, Schenectady, N. Y.
L. W. Chubb, Secretary,
143 W. Swissvale Ave., Swissvale, Pa.
H. H. Norris, Harris J. Ryan,
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W. F. Durand,	L. T. Robinson,
H. W. Fisher,	E. B. Rosa,
H. M. Hobart,	C. E. Skinner,
F. B. Jewett,	H. G. Stott.
P. Junkersfeld,	

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TECHNICAL COMMITTEES

Revised to July 1, 1916

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J. M. Hipple,	A. G. Pierce,
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Revised to July, 1916

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H. W. Buck,	H. A. Lardner,
Frederick Darlington,	E. W. Rice, Jr.,
Gano Dunn,	L. B. Stillwell,

H. G. Stott.

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Gano Dunn,	L. B. Stillwell,
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20 Nassau Street, New York.
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A. E. Kennelly, Secretary,
Harvard University, Cambridge, Mass.

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B. A. Behrend,	Charles F. Scott,
Louis Bell,	Clayton H. Sharp,
James Burke,	Samuel Sheldon,
Gano Dunn,	C. E. Skinner,
H. M. Hobart,	Charles P. Steinmetz,
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R. B. Owens,	Elihu Thomson,
M. I. Pupin,	Philip Torchio.

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29 West 39th Street, New York.

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Louis Duncan,	Charles F. Scott,

Frank J. Sprague.

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New York.

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Dugald C. Jackson,	S. D. Sprong,
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A. S. McAllister,	H. G. Stott,
William McClellan,	P. H. Thomas,
W. S. Murray,	Calvert Townley,

W. D. Weaver.

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Val. A. Fynn,	O. S. Schairer,
L. A. Hawkins,	C. E. Scribner,
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Charles A. Terry.

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H. W. Buck,	John F. Kelly,

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Gano Dunn, A. M. Hunt,
F. N. Waterman.

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S. H. Blake, E. H. Martindale,
H. E. Bussey, O. T. Smith,
L. L. Edgar, E. A. Wagner,
H. A. Hornor, John B. Whitehead,
A. G. Jones, F. E. Wynne.

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105 South La Salle Street, Chicago, Ill.
John Harisberger, A. M. Schoen,
Ralph D. Mershon, Charles W. Stone.

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Appointed by the President for terms of five years.

Term expires July 31, 1916.
Schuyler Skaats Wheeler, Chairman,
Ampere, N. J.
Ralph D. Mershon, Frank J. Sprague.

Term expires July 31, 1917.
A. E. Kennelly, Robert T. Lozier.
S. G. McMeen.

Term expires July 31, 1918.
H. W. Buck, F. A. Scheffler,
J. Franklin Stevens.

Term expires July 31, 1919.
Charles F. Brush, N. W. Storer.

Term expires July 31, 1920.
Carl Hering, Harris J. Ryan,
H. G Stott.

Elected by the Board of Directors from its own membership for terms of two years.

Term expires July 31, 1916.
C. O. Mailloux, L. T. Robinson,
Farley Osgood.

Term expires July 31, 1917.
B. A. Behrend, Paul M. Lincoln
William McClellan.

Ex-Officio.

John J. Carty, President,
George A. Hamilton, Treasurer.
F. L. Hutchinson, Secretary.

INSTITUTE REPRESENTATIVES

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C. O. Mailloux, John J. Carty,

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Samuel Sheldon.

ON LIBRARY BOARD OF UNITED ENGINEERING SOCIETY.

Samuel Sheldon, Harold Pender,
Edward D. Adams, W. I. Slichter,
F. L. Hutchinson.

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The chairman of the Institute's Code Committee.

ON ADVISORY BOARD OF AMERICAN YEAR-BOOK.

Edward Caldwell.

ON ADVISORY BOARD, NATIONAL CONSERVATION CONGRESS.

Calvert Townley.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

W. S. Franklin, G. W. Pierce.

ON CONFERENCE COMMITTEE OF NATIONAL ENGINEERING SOCIETIES.

Calvert Townley, William McClellan.
John J. Carty.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

Charles F. Scott, Samuel Sheldon.

ON AMERICAN ELECTRIC RAILWAY ASSOCIATION COMMITTEE ON JOINT USE OF POLES.

Farley Osgood, F. B. H. Paine,
Percy H. Thomas.

ON NATIONAL JOINT COMMITTEE ON OVERHEAD AND UNDERGROUND LINE CONSTRUCTION.

Farley Osgood, F. B. H. Paine,
Percy H. Thomas.

ON JOINT NATIONAL COMMITTEE ON ELECTROLYSIS.

Bion J. Arnold, F. N. Waterman,
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ON U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ILLUMINATION COMMISSION.

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Clayton H. Sharp.

ON JOINT COMMITTEE ON CLASSIFICATION OF TECHNICAL LITERATURE.

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Benjamin G. Lamme, Frank J. Sprague.

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Robert Julian Scott, Christchurch, New Zealand.
T. P. Strickland, N. S. W. Government Railways, Sydney, N. S. W.
L. A. Herdt, McGill Univ., Montreal, Que.
Henry Graftio, Petrograd, Russia.
Richard O. Heinrich, Genest-str. 5, Schoeneberg, Berlin, Germany.
A. S. Garfield, 67 Avenue de Malakoff Paris, France.
Harry Parker Gibbs, Tata Hydroelectric Power Supply Co., Ltd., Bombay, India.
John W. Kirkland, Johannesburg, South Africa.

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LIST OF SECTIONS

Revised to July 1, 1916.

Name and when Organized	Chairman	Secretary
Atlanta.....Jan. 19, '04	A. M. Schoen	H.E. Bussey, 3d Nat. Bk. Bldg. Atlanta, Ga.
Baltimore.....Dec. 16. '04	J. B. Whitehead	L. M. Potts Industrial Bldg, Baltimore, Md.
Boston.....Feb. 13, '03	Geo. A. Burnham	Ira M. Cushing, 84 State St., Boston, Mass.
Chicago.....1893	W. J. Norton	Taliaferro Milton, 613 Marquette Building, Chicago, Ill.
Cleveland.....Sept. 27, '07	E. W. P. Smith	Bruce W. David, Lincoln Electric Company, Cleveland, Ohio.
Denver.....May 18, '15	H. S. Sands	Robert B. Bonney, Mountain States Tel. and Tel. Co., Denver, Colo.
Detroit-Ann Arbor.....Jan. 13, '11	A. A. Meyer	A. Oakes, American Electrical Heater Company, Detroit, Mich.
Fort Wayne.....Aug. 14, '08	J. J. Kline	J. J. A. Snook, 927 Organ Avenue, Ft. Wayne, Ind.
Indianapolis-Lafayette...Jan. 12, '12	J. L. Wayne, 3rd	Walter A. Black, 3042 Graceland Ave., Indianapolis, Ind.
Ithaca.....Oct. 15, '02	E. L. Nichols	W. G. Catlin, Cornell Univ., Ithaca, N. Y.
Kansas City, Mo......Apr. 14, '16	Gordon Weaver	Glenn O. Brown, Kansas City Elec. Lt. Co., Kansas City, Mo.
Los Angeles.....May 19, '08	E. Woodbury	R. H. Manahan, 32 City Hall, Los Angeles, Cal.
Lynn.....Aug. 22, '11	Gordon Campbell	F. H. Bowman, General Electric Company West Lynn, Mass.
Madison.....Jan. 8, '09	F.A. Kartak	L. E. A. Kelso, University of Wisconsin, Madison, Wis.
Mexico.....Dec. 13, '07		
Milwaukee.....Feb. 11, '10	F. W. Ells	H. P. Reed, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.....Apr. 7, '02	E. T. Street	Walter C. Beckjord, St. Paul Gas Light Co., St. Paul, Minn.
Panama.....Oct. 10, '13	R. H. Whitehead	C. W. Markham, Balboa Heights, C. Z.
Philadelphia.....Feb. 18, '03	H. P. Liversidge	W. F. James, 14th Floor, Widener Bldg., Philadelphia, Pa.
Pittsburgh.....Oct. 13, '02	G. C. Hecker	F. E. Wynne, W. E. and M. Company· East Pittsburgh, Pa.
Pittsfield.....Mar. 25, '04	M. O. Troy	F. R. Finch, General Electric Company, Pittsfield, Mass.
Portland, Ore......May 18, '09	Paul Lebenbaum	L. T. Merwin, Northwestern Electric Co., Portland, Ore.
Rochester.....Oct. 9, '14	O. W. Bodler	Lucien Buck, 1416 Lake Avenue, Rochester, N. Y.
St. Louis.....Jan. 14, '03	W. O. Pennell	George McD. Johns, Room 401, City Hall, St. Louis, Mo.
San Francisco.....Dec. 23, '04	A. H. Babcock	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
Schenectady.....Jan. 26, '03	L. T. Robinson	F. W. Peek, Jr., Gen. Elec. Co., Schenectady, N. Y.
Seattle.....Jan. 19, '04	C. E. Magnusson	C. F. Terrell, Puget Sound Trac. Lt. and Power Co., Seattle, Wash.
Spokane.....Feb. 14, '13	D. F. Henderson	C. M. Fisher, Washingtom Water Power Company, Spokane, Wash.
Toledo.....June 3, '07	W. E. Richards	Max Neuber, Cohen, Freidlander & Martin, Toledo, Ohio.
Toronto.....Sept. 30, '03	H. T. Brandon	Wills Maclachlan, 910 Excelsior Life Building, Toronto, Ont.
Urbana.....Nov. 25, '02	I. W. Fisk	L. V. James, Univ. of Illinois, Urbana, Ill.
Vancouver.....Aug. 22, '11	R. F. Hayward	H. N. Keifer, Northern Electric Company, Ltd., Vancouver, B. C.
Washington, D. C......Apr. 9, '03	Arthur Dunlop	Louis G. Freeman, U. S. Geological Survey, Washington, D. C.

Total 33

LIST OF BRANCHES

Name and when Organized	Chairman	Secretary
Agricultural and Mech. College of Texas.....Nov. 12, '09	A. Dickie	G. B. Hanson.
Alabama, Univ. of.....Dec. 11, '14	Gustav Wittig	A. F. Frazier, University, Ala.
Arkansas, Univ. of.....Mar. 25, '04	A. L. Wilson	W. L. Teague, University of Arkansas, Fayetteville, Ark.
Armour Institute.....Feb. 26, '04	Ralph H. Earle	Harold A. Kleinman, 7743 Burnham Avenue, Chicago, Il.l
Brooklyn Poly. Inst.,...Jan. 14, '16	AlbertH.Bernhard	Walter J. Seeley, The Polytechnic Institute, Brooklyn, N. Y.
Bucknell University....May 17, '10	N. J. Rehman	E. C. Hageman, Bucknell University, Lewisburg, Pa.
California, Univ. of.....Feb. 9, '12	Marc Holzer	C. Maynard, University of California. Berkeley, Cal.
Carnegie Inst. of Tech..May 18, '15	D. L. Trautman	D. F. Gibson, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of.....Apr. 10, '08	C. A. Powell	N. V. McCormick, 3110 Woodburn Avenue Cincinnati, Ohio.
Clarkson Col. of Tech...Dec. 10, '15	W. A. Dart	C. J. Dresser, Clarkson College of Technology, Potsdam, N. Y.
Clemson Agricultural Col. Nov. 8, '12	D. H. Banks	W. H. Neil, Clemson College, S. C.
Colorado State Agricultural College.....Feb. 11, '10	George L. Paxton	Charles F. Shipman, Colorado State Agricultural College, Fort Collins, Colo.

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LIST OF BRANCHES—Continued.

Name and when Organized	Chairman	Secretary
Colorado, Univ. of.....Dec. 16, '04	Charles C. Clymer	Victor E. Leroy, University of Colorado, Boulder, Colo.
Georgia School of Technology.....June 25, '14	C. R. Brown	J. E. Thompson, Georgia School of Technology, Atlanta, Ga.
Highland Park College..Oct. 11, '12	Carl Von Lindeman	C. F. Wright, Highland Park College, Des Moines, Iowa.
Idaho, Univ. of.....June 25, '14	E. R. Hawkins	C. L. Rea, Univ. of Idaho, Moscow, Idaho.
Iowa State College.....Apr. 15, '03	F. H. Hollister	F. A. Robbins, Iowa State College, Ames, Iowa.
Iowa, Univ. of.....May 18, '09	H. W. Matson	A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col...Jan. 10, '08	Walter E. Deal	G. B. McNair, Kansas State Agric. Col., Manhattan, Kansas.
Kansas, Univ. of.....Mar. 18, '08	N. M. Foster	G. M. Bowman, University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. ofOct. 14, '10	H. E. Melton	Margaret Ingels, 251 Delmar Avenue, Lexington, Ky.
Lafayette College.....Apr. 5, '12	Samuel McC.Hunt	Carl Theodore Mack, 418 McCartney Street, Easton, Pa.
Lehigh University.....Oct. 15, '02	F. L. Magee	J. F. Wentz, Lehigh University, South Bethlehem, Pa.
Lewis Institute.....Nov. 8. '07	P B. Woodworth	
Maine, Univ. of.....Dec. 26, '06	Fred P. Jones	G. K. Wadlin, Lambda Chi Alpha House, Orono, Maine.
Michigan, Univ. of.....Mar. 25, '04	A. N. Clarke	F. E. Richardson, University of Michigan, Ann Arbor, Mich.
Minnesota, Univ. of... May 16, '16	Jesse L.Thompson	Donald P. Loye, 4216 Dupont Ave., South, Minneapolis, Minn.
Missouri, Univ. of.....Jan. 10, '03	K. Atkinson	A. C. Lanier, University of Missouri, Columbia, Mo.
Montana State Col.....May 21, '07	Taylor Lescher	J. A. Thaler Montana State College, Bozeman, Mont.
Nebraska, Univ. of.....Apr. 10, '08	Olin J. Ferguson	V. L. Hollister, Station A., Lincoln, Nebr.
North Carolina Col. of Agr., and Mech. Arts.....Feb. 11, '10	R. V. Davis	R. L. Kelly, West Raleigh .N. C.
North Carolina, Univ. of.Oct 9, '14	Edw. Y. Keesler	W. H. Joyner, Univ. of North Carolina, Chapel Hill, N. C.
Ohio Northern Univ.....Feb. 9, '12	H. H. Robinson	F. W. Evans, 302 E. Lincoln Avenue, Ada, Ohio.
Ohio State Univ.....Dec. 20, '02	H. D. Bender	L. W. Birch, 138 Wheatland Avenue, Columbus, Ohio.
Oklahoma, Agricultural and Mech. Col.....Oct. 13, '11	G. E. Davis	W. C. Lane, Oklahoma A. and M. College, Stillwater, Okla.
Oklahoma, Univ. of.....Oct. 11, '12	H. M. Richards	R. E. Heffner, University of Oklahoma, Norman, Okla.
Oregon Agr. Col.....Mar. 24, '08	Winfield Eckley	J. A. Hooper, Oregon Agric. College, Corvallis, Ore.
Penn. State College.....Dec. 20, '02	G. Geracimos	August Heine, State College, Pa.
Pittsburgh, Univ. of....Feb. 26, '14	G. R. Patterson	W. K. Benz, University of Pittsburgh, Pittsburgh, Pa.
Purdue University.....Jan. 26, '03	C. F. Harding	A. N. Topping, Purdue Univ., Lafayette, Indiana.
Rensselaer Poly. Inst....Nov. 12, '09	W. J. Williams	W. R. Townsend, Jr., Rensselaer Polytechnic Institute, Troy, N. Y.
Rose Polytechnic Inst...Nov. 10, '11	H. E. Smock	Sam P. Stone, 1012 North 8th Street, Terre Haute, Ind.
Rhode Island State Col.Mar. 14, '13	C. E. Seifert	Frank A. Faron, Rhode Island State College, Kingston, R. I.
Stanford Univ.....Dec. 13, '07	H. J. Rathbun	J. A. Shepard, Stanford University, Cal.
Syracuse Univ.....Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.....Feb. 14, '08	J. M. Bryant	J. A. Correll, Univ. of Texas, Austin,Tex.
Throop College of Technology.....Oct. 14, '10	J. W. DuMond	K.W. Rich, Throop College of Technology, Pasadena. Cal.
Virginia Polytechnic Institute.....Jan. 8, '15	V. Dixon	John D. Hindle, Virginia Polytechnic Institute, Blacksburg, Va.
Virginia, Univ. of.....Feb. 9, '12	W. S. Rodman	J.H. Moore, Dawsons Row, University,Va.
Wash. State Col. of....Dec. 13, '07	M. K. Akers	H. V. Carpenter, State Coll. of Wash. Pullman, Wash.
Washington Univ.....Feb. 6, '04	Charles A. Lieber	R. W. Macdonald, Washington University, St. Louis, Mo.
Washington, Univ. of...Dec. 13, '12	A. Kalin	J. R. Himmelsbach, University of Washington, Seattle, Wash.
West Virginia Univ.....Nov. 13, '14	C. R. Huffman	H. S. McLaughlin, West Virginia University, Morgantown, W. Va.
Worcester Poly. Inst.....Mar. 25, '04	C. W. Kennedy	J. A. Blair, Worcester Polytechnic Institute, Worcester, Mass.
Yale University.....Oct. 13, '11	A. W. Cahoon	J. P. Allen, Sheffield Scientific School, New Haven, Conn.

Total 55.

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American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXV AUGUST, 1916 Number 8

PACIFIC-COAST CONVENTION

As previously announced, the Pacific-Coast Convention of the A. I. E. E. will be held in Seattle, Wash., September 5 to 9, 1916. The technical program has been completed and all but one of the papers to be presented are published in this issue of the PROCEEDINGS. Advance copies of all of the papers will be distributed at the Convention.

The technical program is as follows:

Tuesday, September 5

MORNING SESSION

Registration

Address of Welcome

Address by President H. W. Buck.

A Distributing System for Domestic Power Service from Commercial and Engineering Standpoints, by Carl H. Hoge and Edgar R. Perry.

AFTERNOON SESSION

Some Features of Domestic Electric Cooking and Heating, by H. B. Pierce.

Temperature Rise of Insulated Lead Covered Cables, by Richard C. Powell.

Wednesday, September 6

MORNING SESSION

Inductive Interference as a Practical Problem, by A. H. Griswold and R. W. Mastick.

AFTERNOON SESSION

Testing for Defective Insulators on High-Tension Transmission Lines, by B. G. Flaherty.

The High Voltage Potentiometer, by Harris J. Ryan.

An Artificial Transmission Line with Adjustable Line Constants, by C. E. Magnusson and S. B. Burbank.

Thursday, September 7

The program for both the morning and afternoon sessions for Thursday will be supplied by the Northwest Electric Light and Power Association.

EVENING SESSION

Lecture "*The Engineer and the Public*" by Henry Suzzallo, President, University of Washington.

Lecture "*Illumination of the Panama-Pacific Exposition*" by W. D'A. Ryan.

Friday, September 8

MORNING SESSION

Characteristics of Admittance Type of Wave Form Standard, by Frederick Bedell.

Insulator Failures Under Transient Voltages, by W. D. Peaslee.

In addition to the technical sessions numerous entertainment features are being arranged, details of which will be announced later.

JOINT MEETING OF A. I. E. E. AND A. I. & S. E. E. SEPTEMBER 18-22, 1916

At the 10th Annual Convention of the Association of Iron and Steel Electrical Engineers, which will be held at

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the Hotel La Salle, Chicago, Ill., September 18-22, 1916, there will be joint sessions with the American Institute of Electrical Engineers on Wednesday, September 20th. Two papers will be presented on behalf of the A. I. E. E. as follows.

Underground Distribution Systems, by George J. Newton.

Steel Conductors for Transmission Lines, by H. B. Dwight.

Both of these papers are published elsewhere in this issue of the PROCEEDINGS, and advance copies of all of the papers will be distributed at the convention. Members of the A. I. E. E. are cordially invited to attend this convention..

MINING ENGINEERS TO MEET IN ARIZONA

The Arizona meeting of the A. I. M. E. will be held September 18 to 25, 1916. There will be a special train from New York City to Arizona and return to accommodate members and guests attending this meeting.

A cordial invitation to attend this meeting has been extended by the A. I. M. E. to members of the American Institute of Electrical Engineers, and the Secretary of the A. I. M. E. will be glad to send printed announcement in regard to the trip to anyone interested. Among the side trips is included an automobile ride over the famous Apache Trail and a visit to the Grand Canyon of the Colorado.

PAST SECTION MEETINGS

Chicago.—Election of officers for the coming year as follows—chairman, Taliaferro Milton; secretary, William J. Crumpton; member of executive committee, William J. Norton.

Denver.—July 18, 1916, Denver Athletic Club. Past-President Lincoln was entertained at luncheon by the Section. Brief addresses by Past-President Lincoln and Chairman-elect Sands. Attendance 28.

Minnesota.—Election of officers as follows: chairman, R. A. Lundquist; secretary, Vernon S. Beck; member of executive committee, A. L. Abbott.

Panama.—June 25, 1916, Gatun, C.Z. Paper: "High Tension Transmission Lines on the Isthmus" by Walter L. Hersh. Attendance 25.

PERSONAL

MR. H. G. HARVEY of the transformer department of the New York district of the General Electric Company has resigned to accept the position of commercial engineer with the Nassau Light and Power Company, Mineola, N. Y. He assumes his new duties August 1, 1916.

MR. H. A. MACKENZIE has returned to Montreal, Canada, for a few months having been deputed by the Kashmir Durbar to investigate the wood stave pipe industry with a view to introducing its manufacture in Kashmir, and also to investigate the latest sawmill machinery.

APPLICATION FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before August 31, 1916.

Andrews, H. L., Schenectady, N. Y.
Barnum, W., Chattanooga, Tenn.
Buell, F. A., Kansas City, Mo.
Cowles, C. C., Bremerton, Wash.
Curtin, W. E., Lynn, Mass.
Duff, S. S., Gold Creek, Mont.
Gooding, R. F., E. Pittsburgh, Pa.
Grigsby, O. E., London, England.

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Heidenreich, A. H. (Member), Akron, O.
Hengstenberg, P. M. (Member), E. Pittsburgh, Pa.
Holmes, A., Washington, D. C.
Hurd, S. J., Chicago, Ill.
Kirkpatrick, E. M., Lynn, Mass.
Klein, F., San Salvadore, Salvador.
Lamb, H. L., Santiago, Chile.
Maxwell, F. R., Tuscaloosa, Ala.
Morse, R. E., La Fundicion, Peru.
Mori, H., New York, N. Y.
Norman, C. L., Oakland, Cal.
Oliver, C., Pittsfield, Mass.
Philip, H. A., New York, N. Y.
Rett, C. E., Akron, O.
Roberts, C. B., Baltimore, Md.
Robinson, E., Boston, Mass.
Robinson, R. W., Universal City. Cal.
Roe, C. H., Flint, Mich.
Rosenblatt, A. M., Coalburg, W. Va.
Rowlands, R. A., Minneapolis, Minn.
Russell, F. L., Newark, N. J.
Shingai, K., Tokyo, Japan.
Smith, H. R. (Member), Boston, Mass.
Smith, H. W., Newark, N. J.
Switzer, F. G., Ampere, N. J.
Thomson, C. S., London, England.
Van der Hoeven, C. (Member), New York, N. Y.
Total 35

EMPLOYMENT DEPARTMENT

Note: Under this heading brief announcements (not more than fifty words in length) of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months: during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

VACANCIES

V-147. Young Technical Graduate for analysis work on operation of public utility properties controlled by a holding company located in New York City. Position offers excellent experience and good opportunity for one proving satisfactory in personal and progressive qualifications.

V-148. Electrical Engineer to take charge of the installation of two 500 kw. generators and induction motors, crane motors, rotary converters etc. After construction is finished, work will include supervision of these installations and other installations owned by the company. Location—New Jersey. Give complete information relative to previous experience and salary expected.

V-149. Permanent position with established company developing an epoch-making mechanical system, for young graduate engineer, with a liking for research work of a practical, semi-commercial nature, preferably with a knowledge of physical chemistry. Must be of a practical bent, and willing to begin at the beginning. A good future for a man who knows how to take advantage of an opportunity. Location—near New York City.

V-150. Electrical Engineering Graduate for writing and composing bulletins on technical apparatus. Permanent position with manufacturer. Only one with past experience desired.

V-151. Young Technical Graduate, with one or two years' experience in testing of electrical machinery and meters. Salary $85-$100 per month.

V-152. The service of a number of men with experience on transmission line work are required for new work in Minnesota. State experience and salary expected.

V-153. Engineering Graduate, designer of small intricate machinery Permanent position.

V-154. Assistant Maintenance Engineer. Should have technical education and experience along lines of power station work, millwright and piping work, drafting and cost work; position pays around $25 to $30 per week, according to experience; location in Mass-

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achusetts. State age, nationality, experience, former places of employment and salary expected.

V-155. Vacancy in publicity department of large manufacturing company. Work includes preparation of catalogues, advertising copy, abstracting of technical articles. Good knowledge of English essential. Ability to read German desirable. Opportunity for advancement.

MEN AVAILABLE

528. Electrical Engineer. Technical graduate, with General Electrical test experience, 27 years of age, married and best of habits. Has had actual experience in preliminary and final calculations, estimates, design and construction of country's largest steam road electrification. Desires position of responsibility with railroad contemplating electrification.

529. Position wanted on Pacific Coast by electrical engineer having five years' experience in design of electrical machinery. At present in engineering department of large Eastern manufacturing company. Desires engineering employment offering opportunity for advancement to conscientious, energetic, competent man. Knowledge of technical German and French. Total abstainer, non-smoker; Californian, age 26.

530. Electrical Engineer would like to get in touch with general manager of an electrical utility in a large or moderate size city. At present employed but wishes to enter a larger field. Has had wide experience in the generation, distribution and utilization of electric power, and in administrative and commercial work.

531. Superintendent. Has had practical experience in all branches of central station work. Now in charge of construction and operation of high tension transmission lines, distribution systems, and plant construction and operation, for large utility company. Age 31; technical education. Desires change with chance of advancement.

532. Engineer, age 33, married. Graduate B. M. E. and E. E. Two years' operating, two and a half years. G. E. test, four years' charge construction work, installing steam turbines. generators, motors and switchboards Employed; reason for change desires permanent location with chance for advancement. Salary $1800.

533. Electrical Engineer, technical graduate, now open for engagement. Three years' testing with manufacturing and central station companies; three years' engineering department of manufacturing company; one year electrical construction; five years' drafting —central station, lighting, telephone, turbines. Business experience.

534. Graduate Electrical Engineer, with three years' engineering experience, and four years commercial and sales engineering experience, will consider an engineering or sales engineering position that does not require constant travelling. Employed at present as sales engineer. Executive ability and good personality. A live man for a real job.

535. Electrical Engineer, Rensselaer and Mass. Inst. Tech. and Westinghouse engineering apprenticeship course. Age 35. Ten years' experience in railway electrification work, powerhouse and boiler-room efficiency work. Experience in engineering, construction and operation. Capable of assuming executive charge or superintending design or construction.

536. Chemical and Electrical Engineer, technical graduate, offers broad experience in industrial research, process design, electrochemistry, furnaces, distillation and highly specialized manufacturing, to the corporation desiring such qualifications, applied with engineering skill, to the betterment of its products.

537. Distribution Engineer. Mem. A. I. E. E. Twenty years' experience in the design, construction and maintenance of underground distribution systems, is open for a position or will design and supervise the construction of underground systems on a commission basis.

538. Manager or Assistant Manager with manufacturing company. Purdue graduate, age 36. New York territory preferred.

539. Electrical Engineer, age 25, 1913 technical graduate, with undergraduate and graduate degrees. Three years graduate work on high tension transmission and the measurement of high voltage. Desires position with consulting engineer or with large manufacturing company. Single, good character, excellent references. Location in the East preferred.

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ACCESSIONS TO LIBRARY

This list includes books on electrical subjects only, which have been added to the library of the A. I. E. E. and the U. E. S. during the past month, not including periodicals and other exchanges.

UNITED ENGINEERING SOCIETY

Bibliographic der Deutschen Zeitschriften Literature. Band XXXVI B. Leipzig, 1915. (Purchase.)

Die Funkentelegraphic. By H. Thurn. Ed. 3. Lpz., 1915. (Purchase.)

Die maschinenlehre der electrischen Zugförderung. By W. Kummer. Berlin, 1915. (Purchase.)

Die Wirkungsweise der Rektifizier und Destillier Apparate. Ed. 3. By E. Hausbrand. Berlin, 1916. (Purchase.)

Electrical Contractor. By L. W. Moxey, Jr. New York, 1916. (Purchase.)

International Engineering Congress. Vol. V—Materials of Engineering Construction. San Francisco, 1916. (Purchase.)

International Engineering Congress. Transactions. Vol. XI—Miscellany. San Francisco, 1915. (Purchase.)

Messungen an elektrischen Maschinen. Ed. 3. By Rudolph Krause. Berlin, 1916. (Purchase.)

GIFT OF AMERICAN ELECTRICAL RAILWAY ASSOCIATION

Bibliography on Valuation of Public Utilities to Dec. 23, 1915. New York, 1915.

GIFT OF CARNEGIE STEEL COMPANY

Axles and Forgings from Steam and Electric Railway Service. Standard Axel Designs and Specifications. Carnegie Steel Company. Pittsburgh, 1915.

GIFT OF GEO. H. GUY

Preliminary notes on a new way of converting light into electrical energy. By Theodore W. Case. (Read before the New York Electrical Society, June 14, 1916.)

GIFT OF MASSACHUSETTS INSTITUTE OF TECHNOLOGY-ELECTRICAL ENGINEERING DEPT.

Oscillating Current Circuits. By V. Bush. n. p. 1916.

GIFT OF NATIONAL FIRE PROTECTION ASSOCIATION

List of Inspected Electrical Appliances. April 1916. Chicago Underwriters' Labroatories, 1916.

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OFFICERS AND BOARD OF DIRECTORS, 1916-1917.

PRESIDENT.
(Term expires July 31, 1917)
H. W. BUCK

JUNIOR PAST-PRESIDENTS.

(Term expires July 31, 1917)
PAUL M. LINCOLN

(Term expires July 31, 1918)
JOHN J. CARTY

VICE-PRESIDENTS.

(Term expires July 31, 1917)
C. A. ADAMS
J. FRANKLIN STEVENS
WILLIAM McCLELLAN

(Term expires July 31, 1918)
B. A. BEHREND
P. JUNKERSFELD
L. T. ROBINSON

MANAGERS.

(Term expires July 31, 1917)
FREDERICK BEDELL
BANCROFT GHERARDI
A. S. McALLISTER
JOHN H. FINNEY

(Term expires July 31, 1918)
C. E. SKINNER
F. B. JEWETT
JOHN B. TAYLOR
HAROLD PENDER

(Term expires July 31, 1919)
CHARLES S. RUFFNER
JOHN B. FISKEN
CHARLES ROBBINS
N. A. CARLE

TREASURER (Term expires July 31, 1917)
GEORGE A. HAMILTON

SECRETARY.
F. L. HUTCHINSON

HONORARY SECRETARY.
RALPH W. POPE

LIBRARIAN.
W. P. CUTTER

GENERAL COUNSEL.
PARKER and AARON,
52 Broadway, New York.

PAST PRESIDENTS.—1884-1916.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMPSON, 1889-90
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-92
FRANK JULIAN SPRAGUE, 1892-3.
*EDWIN J. HOUSTON, 1893-4-5.
*LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-02
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4
JOHN W. LIEB, 1904-5
SCHUYLER SKAATS WHEELER, 1905-6
SAMUEL SHELDON, 1906-7.
HENRY G. STOTT, 1907-8
LOUIS A. FERGUSON, 1908-09.
LEWIS B. STILLWELL, 1909-10.
DUGALD C. JACKSON, 1911-10.
GANO DUNN, 1911-12.
RALPH D. MERSHON, 1912-13.
C. O. MAILLOUX, 1913-14.
PAUL M. LINCOLN, 1914-15.
JOHN J. CARTY, 1915-16.

*Deceased.

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LIST OF SECTIONS

Revised to August 1, 1916.

Name and when Organized	Chairman	Secretary
Atlanta.....Jan. 19, '04	A. M. Schoen	H.E.Bussey,3d Nat. Bk. Bldg. Atlanta,Ga.
Baltimore.....Dec. 16, '04	J. B. Whitehead	L.M.Potts,Industrial Bldg.,Baltimore,Md.
Boston.....Feb. 13, '03	L .L. Elden	Ira M.Cushing,84 State St.,Boston,Mass.
Chicago.....1893	Taliaferro Milton	W. J. Crumpton, 111 W. Monroe St. Chicago, Ill.
Cleveland.....Sept. 27, '07	E. H. Martindale	Irving H. Van Horn, National Lamp Works, Nela Park, Cleveland, Ohio.
Denver.....May 18, '15	W. A. Carter	Robert B. Bonney, Mountain States Tel. and Tel. Co., Denver, Colo.
Detroit-Ann Arbor.....Jan. 13, '11	Ralph Collamore	C. E. Wise, 427 Ford Bldg., Detroit, Mich.
Fort Wayne.....Aug. 14, '08	J. J. Kline	J. J. A. Snook, 927 Organ Avenue, Ft. Wayne, Ind.
Indianapolis-Lafayette..Jan. 12, '12	J. L. Wayne, 3rd	Walter A. Black, 3042 Graceland Ave., Indianapolis, Ind.
Ithaca.....Oct. 15, '02	E. L. Nichols	W. G. Catlin, Cornell Univ., Ithaca, N. Y.
Kansas City, Mo......Apr. 14, '16	Gordon Weaver	Glenn O. Brown, Kansas City Elec. Lt. Co., Kansas City, Mo.
Los Angeles.....May 19, '08	E. Woodbury	R. H. Manahan, 32 City Hall, Los Angeles, Cal.
Lynn.....Aug. 22, '11	G. M. Campbell	M. B. Carroll, Gen. Elec. Co., West Lynn, Mass.
Madison.....Jan. 8, '09	M. C. Beebe	F. A. Kartak, Univ. of Wis.,Madison, Wis.
Mexico.....Dec. 13, '07		
Milwaukee.....Feb. 11, '10	R. B. Williamson	H. P. Reed, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.....Apr. 7, '02	R. A. Lundquist	Vernon S. Beck, Beck Elec. Const. Co., Minneapolis, Minn.
Panama.....Oct. 10, '13	William H. Rose	C. W. Markham, Balboa Heights, C. Z.
Philadelphia.....Feb. 18, '03	J. H. Tracy	W. F. James, 14th Floor, Widener Bldg., Philadelphia, Pa.
Pittsburgh.....Oct. 13, '02	T. H. Schoepf	G. C. Hecker, 436 Sixth Avenue, Pittsburgh, Pa.
Pittsfield.....Mar. 25, '04	M. O. Troy	P. R. Finch, General Electric Company, Pittsfield, Mass.
Portland, Ore.....May 18, '09	Paul Lebenbaum	L. T. Merwin, Northwestern Electric Co., Portland, Ore.
Rochester.....Oct. 9, '14	E. L. Wilder	P.E. Haskell, 93 Monica Street, Rochester, New York.
St. Louis.....Jan. 14, '03	W. O. Pennell	George McD. Johns, Room 401, City Hall, St. Louis, Mo.
San Francisco.....Dec. 23, '04	A. H. Babcock	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
Schenectady.....Jan. 26, '03	L. T. Robinson	P. W. Peek, Jr., Gen. Elec. Co., Schenectady, N. Y.
Seattle.....Jan. 19, '04	C. E. Magnusson	C. F. Terrell, Puget Sound Trac. Lt. and Power Co., Seattle, Wash.
Spokane.....Feb. 14, '13	Victor H. Greisser	C. A. Lund, Washington Water Power Co., Spokane, Washington.
Toledo.....June 3, '07	W. E. Richards	Max Neuber, Cohen, Freidlander & Martin, Toledo, Ohio.
Toronto..... .....Sept. 30, '03	H. T. Brandon	Wills Maclachlan, 910 Excelsior Life Building, Toronto, Ont.
Urbana.....Nov. 25, '02	P. S. Biegler	T. D. Yensen, Univ. of Illinois, Urbana, Ill.
Vancouver.....Aug. 22, '11	R. F. Hayward	H. N. Keifer, Northern Electric Company, Ltd., Vancouver, B. C.
Washington, D.C......Apr. 9, '03	R. H. Dalgleish	Arthur Dunlop, National Electric Supply Company, Washington, D. C.

Total 33

LIST OF BRANCHES

Name and when Organized	Chairman	Secretary
Agricultural and Mech. College of Texas.....Nov. 12, '09	A. Dickie	G. B. Hanson.
Alabama, Univ. of.....Dec. 11, '14	Gustav Wittig	A. F. Frazier, University, Ala.
Arkansas, Univ. of.....Mar. 25, '04	A. L. Wilson	W. L. Teague, University of Arkansas, Fayetteville, Ark.
Armour Institute.....Feb. 26, '04	A. A. Oswald	J. F. Hillock, Armour Institute of Technology, Chicago, Ill.
Brooklyn Poly. Inst.....Jan. 14, '16	AlbertH.Bernhard	Walter J. Seeley, The Polytechnic Institute, Brooklyn, N. Y.
Bucknell University....May 17, '10	N. J. Rehman	E. C. Hageman, Bucknell University, Lewisburg, Pa.
California, Univ. of.....Feb. 9, '12	Marc Holzer	C. Maynard, University of California, Berkeley, Cal.
Carnegie Inst. of Tech..May 18, '15	D. L. Trautman	D. F. Gibson, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of.....Apr. 10, '08	W. A. Steward	R. H. Kruse, 75th and Main Streets, Cincinnati, Ohio.
Clarkson Col. of Tech...Dec. 10, '15	W. A. Dart	C. J. Dresser, Clarkson College of Technology, Potsdam, N. Y.
Clemson Agricultural Col. Nov. 8, '12	D. H. Banks	W. H. Neil, Clemson College, S. C.
Colorado State Agricultural College.....Feb. 11, '10	George L. Paxton	Charles F. Shipman, Colorado State Agricultural College, Fort Collins, Colo.

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LIST OF BRANCHES—Continued.

Name and when Organized	Chairman	Secretary
Colorado, Univ. of.....Dec. 16, '04	E. F. Peterson	Samuel J. Blythe, University of Colorado, Boulder, Colo.
Georgia School of Technology.....June 25, '14	C. R. Brown	J. E. Thompson, Georgia School of Technology, Atlanta, Ga.
Highland Park College..Oct. 11, '12	Carl Von Lindeman	C. F. Wright, Highland Park College, Des Moines, Iowa.
Idaho, Univ. of.....June 25, '14	E. R. Hawkins	C. L. Rea, Univ. of Idaho, Moscow, Idaho.
Iowa State College.....Apr. 15, '03	F. H. Hollister	F. A. Robbins, Iowa St. Col., Ames, Iowa.
Iowa, Univ. of.....May 18, '09	H. W. Matson	A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col...Jan. 10, '08	Walter E. Deal	G. B. McNair, Kansas State Agri. Col., Manhattan, Kansas.
Kansas, Univ. of.....Mar. 18, '08	N. M. Foster	G. M. Bowman, University of Kansas, Lawrence, Kansas.
Kentucky,State Univ.of Oct. 14, '10	H. E. Melton	Margaret Ingels, 251 Delmar Avenue, Lexington, Ky.
Lafayette College.....Apr. 5, '12	Rodman Fox	Frank H. Schlough, Lafayette College, Easton, Pa.
Lehigh University.....Oct. 15, '02	A. F. Hess	R. W. Wiseman, Lehigh University, South Bethlehem, Pa.
Lewis Institute.....Nov. 8, '07	P. B. Woodworth	
Maine, Univ. of.....Dec. 26, '06	A. A. Packard	E. V. Crimmin, Univ. of Maine, Orono, Me.
Michigan, Univ. of.....Mar. 25, '04	U. M. Smith	N. F. Brown, University of Michigan, Ann Arbor, Mich.
Minnesota, Univ. of....May 16, '16	Jesse L. Thompson	Donald P. Loye, 4216 Dupont Ave., South Minneapolis, Minn.
Missouri Univ. of.....Jan. 10, '03	K. Atkinson	A. C. Lanier, University of Missouri, Columbia, Mo.
Montana State Col.....May 21, '07	Taylor Lescher	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of.....Apr. 10, '08	Olin J. Ferguson	V. L. Hollister, Station A., Lincoln, Nebr.
North Carolina Col. of Agr., and Mech. Arts.....Feb. 11, '10	R. V. Davis	R. L. Kelly, West Raleigh, N. C.
North Carolina, Univ. of.Oct. 9, '14	Edw. Y. Keesler	W. H. Joyner, Univ. of North Carolina, Chapel Hill, N. C.
Norwich University.....June 28, '16		
Ohio Northern Univ.....Feb. 9, '12	H. H. Robinson	F. W. Evans, 302 E. Lincoln Av., Ada, O.
Ohio State University....Dec. 20, '02	R. G. Locket	D. A. Dickey, Ohio State University, Columbus, Ohio.
Oklahoma Agricultural and Mech. Col.....Oct. 13, '11	G. E. Davis	W. C. Lane, Oklahoma A. and M. College, Stillwater, Okla.
Oklahoma, Univ. of.....Oct. 11, '12	Clifford O. Oster	W. Miller Vernor, Univ. of Oklahoma, Norman, Okla.
Oregon Agr. Col.....Mar. 24, '08	Winfield Eckley	J. A. Hooper, Oregon Agri. College, Corvallis, Ore.
Penn. State College....Dec. 20, '02	C. L. Knotts	William W. Herold, Jr., State College, Pa.
Pittsburgh, Univ. of....Feb. 26, '14	G. R. Patterson	W. K. Benz, University of Pittsburgh, Pittsburgh, Pa.
Purdue University.....Jan. 26, '03	C. F. Harding	A. N. Topping, Purdue Univ., Lafayette, Indiana.
Rensselaer Poly. Inst...Nov. 12, '09	W. J. Williams	S. N. Galvin, Rensselaer Polytechnic Institute, Troy, N. Y.
Rose Polytechnic Inst...Nov. 10, '11	H. E. Smock	Sam P. Stone, 1012 North 8th Street, Terre Haute, Ind.
Rhode Island State Col.Mar. 14, '13	C. E. Seifert	Frank A. Faron, Rhode Island State College, Kingston, R. I.
Stanford Univ.....Dec. 13, '07	A. B. Stuart	H. J. Rathbun, Stanford University, Cal.
Syracuse Univ.....Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.....Feb. 14, '08	J. M. Bryant	J. A. Correll, Univ. of Texas, Austin, Tex.
Throop College of Technology.....Oct. 14, '10	J. W. DuMond	K.W. Rich, Throop College of Technology, Pasadena, Cal.
Virginia Polytechnic Institute.....Jan. 8, '15	V. Dixon	John D. Hindle, Virginia Polytechnic Institute, Blacksburg, Va.
Virginia, Univ. of.....Feb. 9, '12	W. S. Rodman	J.H. Moore, Dawsons Row, University, Va.
Wash, State Col. of.....Dec. 13, '07	M. K. Akers	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.....Feb. 6, '04	P. C. Roberts	Charles A. Lieber, Washington University, St. Louis, Mo.
Washington, Univ. of...Dec. 13, '12	E. C. Miller	Geo. S. Smith, Univ. of Washington, Seattle, Wash.
West Virginia Univ.....Nov. 13, '14	H. C. Schramm	C. L. Walker, West Virginia Univ., Morgantown, W. Va.
Worcester Poly. Inst....Mar. 25, '04	R. M. Thackeray	C. C. Whipple, Worcester Polytechnic Institute, Worcester, Mass.
Yale University.....Oct. 13, '11	A. W. Cahoon	J. P. Allen, Sheffield Scientific School, New Haven, Conn.

Total 56.

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American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXV SEPTEMBER, 1916 Number 9

PACIFIC COAST CONVENTION

As announced in previous issues of the PROCEEDINGS, the Pacific Coaast Convention of the A. I. E. E. will be held in Seattle, Wash., September 5th to 9th, 1916. The headquarters during the convention will be at the Hotel Washington where the technical sessions will be held. All of the papers for this meeting have been previously published in the PROCEEDINGS except one by Messrs, Griswold and Mastick entitled "Inductive Interference as a Practical Problem". This paper will be found elsewhere in this issue.

JOINT MEETING IN CHICAGO WITH A. I. AND S. E. E.

The joint meeting of the A. I. E. E. and A. I. & S. E. E. will be held September 18-22, 1916, as previously announced. The joint sessions will be held Wednesday, September 20 at which the papers by Messrs. Newton and Dwight, which have been published previously in the PROCEEDINGS will be presented on behalf of the A. I. E. E. At 7:00 p.m. of the same day will be held the Annual Banquet and Ball, to which ladies are especially invited.

INSTITUTE MEETING, PHILADELPHIA, OCTOBER 13, 1916

The 325th meeting of the A. I. E. E. will be held in Philadelphia, October 13, 1916. The general subject of the meeting will be "Electrical Supply for Large Single-Phase Load". The subject will be covered by four papers, two of which will be by representatives of the operating companies and two by representatives of the manufacturing companies. There will be both afternoon and evening sessions. The program for the afternoon session will comprise papers by Messrs. W. C. Eglin and Philip Torchio, representing the operating companies. In the evening will be presented the two papers representing the manufacturing companies, the titles and authors of which will be announced later. The meeting will be held at the University of Pennsylvania, and an informal dinner will take place between the sessions.

DIRECTORS' MEETING, NEW YORK, AUGUST 8, 1916

The first meeting of the Board of Directors of the Institute for the administrative year beginning on August 1, 1916, was held in New York on Tuesday August 8, at 3 p.m.

There were present: President H. W. Buck, New York; Past-President Paul M. Lincoln, Pittsburgh, Pa.; Vice-Presidents C. A. Adams, Cambridge, Mass., B. A. Behrend, Boston, Mass., L. T. Robinson, Schenectady, N. Y.; Managers Bancroft Gherardi and A. S. McAllister, New York. John H. Finney, Washington, D. C., C. E. Skinner and Charles Robbins, Pittsburgh, Pa., John B. Taylor, Schenectady, N. Y., Charles S. Ruffner, St. Louis, Mo., N. A. Carle, Newark, N. J.; Treasurer George A.

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Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

President Buck announced appointments on various Institute Committees for the administrative year beginning August 1, 1916. The chairmen of the committees appointed are as follows: Finance, J. Franklin Stevens, Philadelphia, Pa.; Board of Examiners, A. S. McAllister, New York; Editing, W. I. Slichter, New York; Meetings and Papers, L. T. Robinson, Schenectady, N. Y.; Sections, Walter A. Hall, West Lynn, Mass.; Public Policy, Calvert Townley, New York; Development of Water Power, John H. Finney, Washington, D. C.; Patent, Ralph D. Mershon, New York; U. S. National Committee of the International Electrotechnical Commission, C. O. Mailloux, New York; Reserve Corps of Engineers, Bion J. Arnold, Chicago, Ill. Representatives were also appointed on various joint committees and other bodies. Additional committees will be appointed later.

The Board elected from its own membership Messrs. C. A. Adams, C. E. Skinner and Harold Pender, to serve upon the Edison Medal Committee for the term of two years, to fill the places of members whose terms had expired.

The Board reappointed the following Local Honorary Secretaries for the term of two years ending July 31, 1918: L. A. Herdt, Canada; Robert Julian Scott, New Zealand; Henry Graftio, Russia; A. S. Garfield, France; T. P. Strickland, New South Wales; Harry Parker Gibbs, India, John W. Kirkland, South Africa.

Two additional appointments were made by the Board for the same period; namely, James S. Fitzmaurice, West Australia; and W. G. T. Goodman South Australia.

It was voted to rename some of the existing technical committees as follows:

Old Name:	New Name:
Transmission	Transmission and Distribution.
Railway	Traction and Transportation.
Industrial Power	Committee on Electricity for Industrial and Domestic use.
Electric Lighting	Lighting and Illumination
Protective Apparatus	Protective Devices
Electrochemical	Electrochemistry and Electrometallurgy.
Records and Appraisals of Properties	Committee on Economics of Electric Service.

Upon recommendation of President Buck and the Meetings and Papers Committee, the decision made at the June Board meeting to hold an Institute meeting in Philadelphia in October and to omit the usual New York meeting was reaffirmed.

It was also voted to hold the usual November meeting in New York, and an Institute meeting in Boston in December, omitting the New York meeting that month. In each case the Board of Directors will meet on the same date and in the same city in which the Institute meeting is held.

The report of the Board of Examiners of its meeting held on August 3 was read and the actions taken at that meeting were approved.

Upon the recommendation of the Board of Examiners 14 students were ordered enrolled, 102 applicants were elected as Associates, five were elected to the grade of Member, 18 were transferred to the grade of Member, and two were transferred to the grade of Fellow. The names of all of these applicants will be found elsewhere in this issue.

A considerable amount of other business was transacted by the Board at this meeting, reference to which will be found under appropriate headings in this and future issues of the PROCEEDINGS.

NEW YORK OCTOBER MEETING OF A. I. E. E. OMITTED

At the meeting of the Board of Directors of the Institute held on June 28, during the Annual Convention, it was decided to hold an Institute meeting in Philadelphia in October, and to omit the usual New York meeting that

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month. This action was confirmed at the meeting of the Board of Directors held August 8, and a notice of the October meeting to be held in Philadelphia will be found elsewhere in this issue.

CIVIL ENGINEERS HEADQUARTERS TO BE IN ENGINEERING SOCIETIES BUILDING

It is with much pleasure that we are now able to announce that the American Society of Civil Engineers has decided to establish its headquarters in the Engineering Societies Building, and has already entered the United Engineering Society as a Founder Society on the same basis as the American Society of Mechanical Engineers, the American Institute of Mining Engineers, and the American Institute of Electrical Engineers.

Active negotiations with the object of bringing about this exceedingly desirable result date back to June 24, 1915, when the following resolution was adopted by the Trustees of the United Engineering Society:

RESOLVED, that out of its desire to welcome the American Society of Civil Engineers into the fraternity of the Founder Societies and with a sense of the increased dignity and usefulness to the engineering profession which this adherence of the American Society of Civil Engineers would contribute, the United Engineering Society hereby desires to express the sentiment in favor of coalition which has been growing, to invite the American Society of Civil Engineers to consider entering the United Engineering Society as an additional Founder Society: and the president is authorized to appoint a committee to confer with any corresponding Committee of the American Society of Civil Engineers in the formation of a tentative plan which if this invitation is accepted can be referred on the part of the United Engineering Society to the governing bodies of the Founder Societies for their action.

Many conferences were held by Committees representing the American Society of Civil Engineers and the United Engineering Society, and the question of moving the headquarters of the American Society of Civil Engineers was finally submitted to the corporate members of that Society by letter ballot, the result of which was announced in June, 1916. The vote was 2,500 in favor of and 390 against the proposed change in headquarters.

On June 23, 1916, the Board of Direction of the American Society of Civil Engineers adopted resolutions accepting the invitation of the United Engineering Society as embodied in the resolution quoted above and which had already been approved by the governing bodies of the American Society of Mechanical Engineers, the American Institute of Mining Engineers and the American Institute of Electrical Engineers.

The details of the arrangement finally agreed upon are given in the following Memorandum of Agreement which has been entered into between the various societies concerned by authority of their respective governing bodies.

MEMORANDUM AGREEMENT

Between United Engineering Society
American Institute of Electrical Engineers
The American Society of Mechanical Engineers
American Institute of Mining Engineers
and
The American Society of Civil Engineers

Memorandum of Agreement entered into this twenty-fifth day of July, 1916, between UNITED ENGINEERING SOCIETY, party of the first part, AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, party of the second part, THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, party of the third part, AMERICAN INSTITUTE OF MINING ENGINEERS, party of the fourth part, and THE AMERICAN SOCIETY OF CIVIL ENGINEERS, party of the fifth part.

The party of the first part being incorporated by an Act of the Legislature of the State of New York which became a law May 11th, 1904, and being the owner of premises consisting of land and its Building erected thereon known as the Engineering Societies

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Building, and located on West 39th Street, in the Borough of Manhattan, in the City of New York, and the parties of the second, third, and fourth parts hereto, being Founder Societies of the party of the first part, and an invitation having been extended by the party of the first part to the party of the fifth part to enter into the Fraternity of said Founder Societies by becoming a Founder Society of the party of the first part, such invitation meeting with the hearty approval of the parties of the second, third and fourth parts hereto and the same having been accepted by the party of the fifth part hereto.

Now, for the purpose of consummating the plan for the entry of the party of the fifth part as such Founder Society which has been agreed to between the parties hereto, this Agreement *Witnesseth*:

First: The parties hereto and each of them do hereby agree that the party of the fifth part shall become a founder Society of the party of the first part with like rights and relations in and with the party of the first part and with each of the other parties hereto as those now possessed and existing by and between the parties of the first, second, third and fourth parts.

Second: To that end the parties of the second, third, fourth and fifth part hereto and each of them do hereby request the party of the first part to enlarge its building above mentioned by adding thereto three additional stories as provided for by plans heretofore filed in the Building Department by Henry G. Morse, Architect, with such modifications as may be requisite or appropriate to meet legal requirements or as may be approved of by the Architect and the building Committee of the party of the first part and the party of the first part agrees so to do. The cost of making such enlargement not exceeding, however, the sum of $250,000 will be paid by the party of the fifth part as its contribution as a Founder Society, and in lieu of the contribution which said party of the fifth part would have made under the Founder's Agreement between the aforementioned Founder Societies and the party of the first part, if the party of the fifth part had been originally a Founder Society of the party of the first part. The amount so contributed by the party of the fifth part shall be paid and advanced under and upon the terms of the Treasurer's receipts of the party of the first part which shall be issued to the party of the fifth part at par for the amounts so contributed or advanced from time to time, in the same form as Treasurer's receipts provided for in said Founder's Agreement, and the rights of the party of the fifth part growing out of, or respecting such contribution shall be identical with the rights of the existing Founder Societies respectively growing out of the payments or contributions made by them evidenced by Treasurer's receipts provided for in said Founder's Agreement. In arriving at cost of enlargement under this contract interest at the rate of four and one-half per cent (4½%) on payments made prior to the completion of such enlargment shall be deemed to be part of such cost.

Third: The party of the first part agrees that any excess over the sum of $250,000 in the cost of making the above mentioned enlargement to its building will be borne and paid by the party of the first part.

Fourth: Upon the party of the fifth part becoming a Founder Society its Library shall be added to the joint Library of the parties of the first, second, third and fourth parts to be controlled and administered as one joint Library by the Library Board of the United Engineering Society in accordance with the By-Laws of such Society, and each of the parties hereto agrees that upon the party of the fifth part becoming a Founder Society, it will enter into a Library Agreement with respect to such joint Library as increased by the Library of the party of the fifth part, which said agreement shall, with the omission of paragraphs "9th" and

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"10th" thereof, and the addition of the party of the fifth part as a party thereto, be in like form as the existing Library Agreement between the existing Founder Societies and the party of the first part.

Fifth: The parties hereto severally agree that upon the party of the fifth part becoming a Founder Society they will enter into a new Founder's Agreement which shall supplant and be a substitute for the existing Founder's Agreement, and which said new Agreement shall read as follows, to wit:

MEMORANDUM OF FOUNDERS AGREEMENT entered into this day of 191, between UNITED ENGINEERING SOCIETY party of the first part, AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, party of the second part, THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, party of the third part, AMERICAN INSTITUTE OF MINING ENGINEERS, party of the fourth part, and THE AMERICAN SOCIETY OF CIVIL ENGINEERS, party of the fifth part.

The party of the first part being incorporated by an Act of the Legislature of the State of New York which became a law May 11th, 1904, and being the owner of land and a building erected thereon known as the Engineering Societies Building, located on West 39th Street, in the Borough of Manhattan, in the City of New York, and the parties of the second, third and fourth parts having been heretofore Founder Societies of the party of the first part, and having together with said party of the first part on or about January 26th, 1905, executed an agreement known as the Founder's Agreement as provided for in the By-Laws of the party of the first part, and the party of the fifth part having become an additional Founder Society of the party of the first part, with like rights and relations in and with the party of the first part, and with the parties of the second, third and fourth parts, as those heretofore possessed and existing by and between the parties of the first, second, third and fourth parts, and the parties of the second, third and fourth parts having heretofore each made certain payments or advances by way of contribution to the United Engineering Society under and upon the terms of the Treasurer's receipts, provided for in said Founder's Agreement, and the party of the fifth part hereto having heretofore agreed, as its contribution to said United Engineering Society, and in lieu of the contribution which it would have made under said original Founder's Agreement if it had been originally a Founder Society, to pay the cost of the enlargement of the said building not exceeding however, the sum of $250,000 as is more fully provided for by agreement between the parties hereto dated the day of 191 , such contribution by the party of the fifth part to be made under and upon the terms of the Treasurer's receipts of the party of the first part hereinafter set forth, and

Whereas, for the aforementioned contributions heretofore made by each of the parties of the second, third and fourth parts, such treasurer's receipts have been issued, and

Whereas, the parties of the second, third, fourth and fifth parts hereto are desirous of enjoying the privileges of Founder Societies of the said party of the first part as provided for in the By-Laws of the said United Engineering Society, now these presents *Witnesseth*:

The parties of the second, third, fourth and fifth parts do severally, each for themselves and not for each other, promise and agree to and with each other and with the party of the first part, to permanently maintain their principal offices in the building of the party of the first part, subject to the provisions of the By-Laws of the United Engineering Society as they now exist or may hereafter be amended, such agreements of the parties of the second, third and fourth parts being effective now, and such agreement of the party of the fifth part to become effective from, and beginning with the time of the completion of the enlargement above mentioned. The amounts heretofore contributed to the party of the first part by the parties of the second, third and fourth parts having been paid and advanced under and upon the terms of the Treasurer's receipts of the party of the first part issued at par for the amounts so paid or advanced from time to time in the following form, it is agreed that the contribution of the party of the fifth part for, or towards the cost of making the enlargement of the building hereinabove mentioned, not exceeding the sum of $250,000 shall likewise be paid and advanced under and upon the terms of such Treasurer's receipts of the party of the first part, which shall be issued at par for the amounts so paid or advanced from time to time, such Treasurer's receipts to be in the following form, to wit:

TREASURER'S RECEIPTS

This Certifies that United Engineering Society (herein called the payee) has received from American of Engineers (herein called the payor) the sum of ($) to be used and invested by the payee in carrying out its corporate purposes, said amount being so paid as part consideration for the admission of the payor as a Founder Society of the payee, under and subject to the by-laws of the payee.

It is Agreed by the payor that interest on the amount of this receipt is and will be deemed discharged by privileges accorded to the payor as a Founder Society as provided in the by-laws of the payee, and that no right to recover any of the principal of such amount or interest thereon, shall exist so long as the payee shall be in existence and perform its corporate functions. Neither this receipt nor the claim for the amount evidenced thereby is transferable and any assignment or encumbrance of said receipt or claim,

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shall make the same void. Neither this receipt nor said claim shall be redeemable or payable excepting out of such portion of the reserve fund of the payee as may be appropriated therefor by a vote of the majority of the representitaves of each of the Founder Societies on the Board of Trustees of the payee, as such Board shall then be constituted, it being understood that any such appropriation, if made, shall be applied pro rata upon such claims represented by treasurer's receipts issued to and then held by such Founder Societies as shall then be represented in the Board of Trustees of the payee. This receipt and the claim evidenced thereby, shall not be subject to any indebtedness of the payor to the payee and shall become void as an evidence of indebtedness or obligation to said payor in case said payor shall for any cause cease to have representation upon the Board of Trustees of the payee.

UNITED ENGINEERING SOCIETY.
.....*Treasurer.*
.....*President.*
Dated, New York.....19 .

And each of the Parties of the second, third, fourth and fifth parts hereto does further covenant and agree severally, and each only for itself, to and with each other, and to and with the party of the first part, that it will abide by and comply with the by-laws of the party of the first part and will pay when due all assessments levied against it, in accordance with the by-laws of the party of the first part. The party of the first part, in consideration of this agreement, has adopted its by-laws, and has admitted or will admit the parties of the second, third, fourth and fifth parts hereto, as Founder Societies, in accordance with the provisions thereof, and has acquired property and assumed obligations for the purpose, among other things, of enabling it to accord privileges in its building to the parties of the second, third and fourth and fifth parts, and this instrument is executed by the parties of the second, third, fourth and fifth parts hereto in consideration thereof, and to induce said party of the first part to take such action. And each of the several parties hereto has assumed the obligations herein contained in consideration of the agreements and obligations of each of the other parties hereto.

This agreement is entered into in lieu of, and as a substitute for the Founder's Agreement heretofore entered into between the first four parties hereto, it being agreed however, that the Treasurer's receipts heretofore issued pursuant to the original Founder's Agreement shall remain operative and of the same order of validity and priority as Treasurer's receipts to be issued hereunder to the party of the fifth part.

In Witness Whereof, the several parties hereto have caused these presents to be executed by their respective officers and their corporate seals to be hereunto affixed.

Sixth: The parties hereto severally agree that they will, with all convenient speed, cause the By-Laws of the party of the first part to be amended in such respects as may be necessary to carry into effect the purposes of this Agreement, and that they will do and cause to be done, such acts and execute such instruments as may be necessary or reasonably appropriate to carry into effect such purposes.

Seventh: Pending the completion of the enlargement of said building and in anticipation of the formal execution of this instrument by the parties of the second, third and fourth parts hereto the parties of the first and fifth parts may, upon the execution of this agreement by them, proceed with the aforementioned enlargement of said building and any sums paid or advanced in that behalf by the party of the fifth part shall be deemed to be paid and advanced towards such enlargement under and pursuant to the terms and provisions of this agreement. With respect to any payments required to be made from time to time for the cost of the above mentioned enlargement, the party of the fifth part shall have thirty days from notice to it by the Building Committee that such amount will be required, within which to pay the same.

Eighth: No assessment for space other than in connection with the Library shall be made against the party of the fifth part until the Building Committee shall certify that the above mentioned enlargement is ready for occupancy.

Ninth: Annexed hereto, marked "A" is a copy of the Charter and By-Laws of the party of the first part,and annexed hereto, marked "B" and "C" are copies of notices of proposed amendments to the By-Laws of the party of the first part, and annexed hereto, marked "D" is a copy of the Library Agreement hereinabove referred to, and the first four parties hereto agree that they will cause the adoption of said amendments and of each of them as soon as practicable.

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In Witness Whereof, this Agreement has been executed by the representatives of the respective parties hereto thereunto unto duly authorized and the seals of the respective parties hereto have been hereunto duly affixed the day and year first above mentioned.

UNITED ENGINEERING SOCIETY
By Charles F. Rand, *President*,
Jos. Struthers, *Treasurer*.
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
By H. W. Buck, *President*,
F. L. Hutchinson, *Secretary*.
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
By D. S. Jacobus, *President*,
Calvin W. Rice, *Secretary*.
AMERICAN INSTITUTE OF MINING ENGINEERS
By L. D. Ricketts, *President*,
Bradley Stoughton, *Secretary*.
THE AMERICAN SOCIETY OF CIVIL ENGINEERS
By Clemens Herschel, *President*,
Chas. Warren Hunt, *Secretary*
J. Vipond Davies, *Director*.

At its meeting of August 10th, 1916, the United Engineering Society made the necessary changes in its by-laws, and the American Society of Civil Engineers became one of the four Founder Societies. Its representatives in the United Engineering Society are Clemens Herschel, Charles Warren Hunt, and J. Vipond Davies.

On July 6, 1916, the President of the United Engineering Society appointed the following building committee consisting of a representative from each of the four societies,—H. H. Barnes, Jr., Chairman, Henry G. Stott, Charles Warren Hunt, and Charles F. Rand. This Committee has held a number of meetings and has awarded a contract for preliminary structural work and this work was started by the contractor July 29, 1916.

The engineering profession is to be congratulated upon the opportunity of closer cooperation on matters affecting the interests of the entire profession, which will be afforded by the consumation of this plan, which unites in one building the headquarters of the four principal engineering societies of America.

COMING SECTION MEETINGS

Kansas City.—Early in October. Paper: "Electric Applications in Oil Fields", by W. F. Barnes.

Pittsburgh.—September 12, 1916. Joint meeting with the Jovians in the English Room of the Fort Pitt Hotel. Meeting will be preceded by a dinner to be served at 6:30 p.m., during which entertainment will be furnished.

October 10, 1916. Joint meeting with the Association of Iron and Steel Electrical Engineers to discuss papers presented at the September convention in Chicago.

Rochester.—September 22, 1916. Paper: "Some Little Recognized Factors in the Use of Power Limiting Reactors" by John C. Parker.

PAST SECTION MEETINGS

Panama.—July 30, 1916, Balboa Heights, C. Z., Paper: "The Telephone System of the Panama Canal", by Charles L. Bleakly. An inspection of the Balboa Heights telephone exchange followed the meeting. Attendance 51.

Vancouver.—June 1, 1916, Board of Trade Rooms. Annual meeting of Vancouver Section. Reelection of present officers to act during the coming year.

PERSONAL

MR. JOHN F. VAUGHAN, for the last fourteen years with Stone and Webster organization, announces that he has opened an office at 185 Devonshire Street, Boston, for the general practise of engineering.

Dr. William McClellan, consulting engineer of New York City, has been appointed Dean of the Wharton School of Finance and Commerce of the Uni-

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versity of Pennsylvania. Dr. McClellan will do no teaching but will devote his efforts to furthering the interests of the school which is one of the principal undergraduate departments of the University with more than 2,000 students.

Dr. McClellan is a Fellow and Vice-President of the A. I. E. E. and a member of its Public Policy Committee and Representative of the Institute on the Joint Conference Committee of Engineering Societies, and previous to his entrance in the electrical engineering field he spent a number of years in university and preparatory school teaching.

MR. AXEL J. STAHL, formerly with the General Electric Company at Schenectady, for several years engineer with the British Thomson-Houston Company, and chief electrical engineer of Graham Brothers in Stockholm, Sweden, has organized his engineering firm in that city into a limited corporation, which will carry on a business of general engineering and the merchandising of engineering materials. The business of A. J. Stahl and Company is divided into four departments: electrical engineering, machine tools, iron and steel, and civil engineering, the latter department including machinery for road building, railroads, shipyards and quays, and compressed air machinery. The company is desirous of getting in touch with American manufacturers who wish to push their sales in Scandinavia, Finland and Russia.

MR. C. LE MAISTRE, General Secretary of the International Electrotechnical Commission, who recently visited the United States as a delegate of the Engineering Standards Committee of Great Britain to the meetings of the Standards Committee of the American Institute of Electrical Engineers, has been appointed Secretary of the Engineering Standards Committee of Great Britain with permission to continue his I. E. C. connection and also his consulting work. Mr. le Maistre has been one of the prime movers in the field of international standardization since its inception, and the ability he has displayed and the success he has achieved in this work particularly qualify him for the important post to which he has been appointed. During his visit to this country he gave most generously of his time to the Standards Committee in all kinds of conferences, where he rendered most valuable assistance. Finally he delayed his departure from this country in order to attend the Cleveland Convention of the Institute where he presented a stimulating paper on "Standardization" which appears in this issue of PROCEEDINGS.

OBITUARY

HAROLD LOMAS, Assoc. A. I. E. E., formerly of New York, lieutenant of the Twentieth Manchester Regiment, was killed in action in France July 1, 1916. Lieutenant Lomas was born in Manchester, England, forty-two years ago. He was graduated from Manchester Academy and Victoria University, where he took engineering honors. He came to New York in 1900 and was connected with the Crocker-Wheeler Company. After the outbreak of the war he returned to England, obtained his commission, and was sent to the front on November 5, 1915. He was elected an Associate of the Institute May 19, 1903

JUDSON H. BOUGHTON, Mem. A. I. E. E., president of the Great Lakes Boat Building Corporation of Milwaukee, Wis., died in that city on July 29, 1916, in his thirty-eighth year, as the result of injuries received in a fire on his motor boat. Mr. Boughton was graduated from Cornell University in 1903, and from 1907 to 1915 he was interested in the operation of electric light and street railway companies in the South and Southwest. He had been president of the Citizens Railway Company of Waco, Texas, and consulting engineer for the Ft. Worth Light and Power Company, and for the St.

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Francis Railroad of Missouri, and had been connected with several other public utility companies during this period. He was elected an Associate of the Institute May 18, 1909, and was transferred to the grade of Member June 27, 1912.

CHARLES SUMNER CHAMPION, Mem. A. I. E. E., a well-known patent lawyer of New York, died at Savona, N. Y., July 31, 1916, after an illness of several months. He was born in Washington, D. C., January 22, 1871. He studied at the New York University Law School, and since 1888 had been engaged in the practise of patent law in Washington, Philadelphia, Hartford and New York. In his work he had been engaged in the patent causes of many American and European inventors, including Thomas A. Edison, Francis H. Richards, Dr. Werner von Siemens, and Charles R. Underhill. Mr. Champion was elected as a Member of the Institute December 10, 1915.

RECOMMENDED FOR TRANSFER AUGUST 3, 1916

The Board of Examiners, at its regular monthly meeting on August 3, 1916, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Member

BARFOED, SVEND, Electrical and Hydraulic Engineer, California Power & Mfg. Co., San Francisco, Cal.

BILLINGS, W. C., Supt., Power and Light Div., Cumberland County Power and Light Co., Portland, Me.

BIXBY, WILLIAM P., Electrical Engineer Nashville, Chattanooga & St. Louis Railway, Nashville, Tenn.

EAGER, WILLIAM C., Second Vice-President and General Manager, Valdosta Lighting Co., Valdosta, Ga.

FARWELL, STANLEY P., Chief of Service Dept., State Public Utilities Commission of Illinois, Springfield, Ill.

NISAR, A. R., Head Assistant Professor, Electrical Dept., Central Technological Institute, Bombay, India.

SINCLAIR, STEPHEN L., Electrical and Mechanical Superintendent, U. S. Reclamation Service, Williston, N. D.

SUMMERHAYES, HENRY R., Assistant Engineer, Lighting Dept., General Electric Co., Schenectady, N. Y.

TRANSFERRED TO THE GRADE OF FELLOW AUGUST 8, 1916

The following Members were transferred to the grade of Fellow of the Institute at the meeting of the Board of Directors on August 8, 1916.

BURTON, PAUL GIBSON, Engineer, Chesapeake and Potomac Tel. Co. and Associated Cos., Baltimore, Md.

MITCHELL, JAMES, Alabama Power Co., New York, N. Y.

TRANSFERRED TO THE GRADE OF MEMBER AUGUST 8, 1916

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on August 8, 1916.

BLACKALL, FREDERICK S., Vice-President and General Manager, Taft-Peirce Mfg. Co., New York, N. Y.

CHELLIS, GEORGE FREDERICK, Electrical Engineer, J. G. White Engineering Corp., San Francisco, Cal.

COAHRAN, JESSE MYERS, Professor of Electrical Engineering, Villanova College, Villanova. Pa.

DATE, WILLIAM EDSON, Engineer, Cutler-Hammer Mfg. Co., New York, N. Y.

DEAN, PETER P., Consulting Engineer, New York, N. Y.

FRANCISCO, FERRIS LEROY, Consulting Engineer, New York, N. Y.

HALL, ARTHUR JOHN, Railway Control Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

HERZ, ALFRED, Public Service Co. of Northern Illinois, Chicago, Ill.

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INGERSLEV, KAY, Electrical Engineer, c/o Siam Electrical Co., Ltd., Bangkok, Siam.

JEFFERIES, ERNEST SMITH, Electrical Engineer, Steel Co., of Canada, Hamilton, Ont.

KEIFER, HAROLD NEIL, Sales Engineer, Northern Electric Co., Vancouver, B. C.

LYON, JESSE D., Consulting Engineer, Cincinnati, O.

ROCHESTER, THOMAS W., Electrical Engineer, Board of Estimate, New York, N. Y.

SHEPPARD, H. S., Assistant Professor of Electrical Engineering, University of Michigan, Ann Arbor, Mich.

VINCENT, H. B., Operating Engineer, Day & Zimmermann, Philadelphia, Pa.

WALLOWER, EDGAR Z., General Manager, Lockport Light, Heat & Power Co., Lockport, N. Y.

WESTBURG, PAUL A., President, Badt-Westburg Electric Co., Chicago, Ill.

WILLIAMS, SAMUEL BYRON, JR., Telephone Engineer, Western Electric Co., New York, N. Y.

MEMBERS ELECTED AUGUST 8, 1916

DAY, ADDISON BLANCHARD, Manager of Operation, Los Angeles Gas and Electric Corp., 645 S. Hill St., Los Angeles, Cal.

FLANDERS, LOUIS HEGUEMBOURG, Assistant Engineer, Dept. of Development and Design, Electric Storage Battery Co., Philadelphia; res., 240 Wyncote Rd., Jenkintown, Pa.

MOREHOUSE, LYMAN FOOTE, Equipment Engineer, American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

STREET, GEORGE TATUM, Western Representative, James Snyder Co., 303 Mahoning Bank Bldg., Youngstown, Ohio.

WELLER, FRANCIS R., Consulting Engineer, Hibbs Building, Washington, D. C.

ASSOCIATES ELECTED AUGUST 8, 1916

ANDERSON, CLAUDE E., Inspector, Electric Division, Panama Canal, Balboa Heights; res., Ancon, Canal Zone.

ANDREWS, ROBERT MORRIS, Passenger Agent, Baltimore & Ohio Railroad Co., Parkersburg, W. Va.

*APESECHE, RUFINO FRANCISCO, Italo-Argentine Electrical Co., Buenos Aires, Argentine Republic.

ARCHILA, M. OCTAVIO, Asst. to High Tension Constructing Engineer, Rio de Janeiro Tramway, Light & Power Co., Rio de Janeiro, Brazil, South America.

ARMSTRONG, E. R., Mechanical Superintendent, E. I. du Pont de Nemours & Co., Hopewell Works, City Point, Va.

BACH, WALLIS KARL, Assistant Test Engineer, Sperry Gyroscope Co., 126 Nassau St., Brooklyn, N. Y.

BECHLEM, ALFRED W., Control House Operator, Panama Canal, Gatun, Canal Zone.

BOLLINGER, HOWARD MOORE, Special Inspector, Central District Telegraph Co.; res., 1230 Mississippi Ave., Pittsburgh, Pa.

BOSWELL, WALTER OSLER, Electrical Engineer, Ontario Hydro Electric Power Commission; res., 25 Roxborough St. West, Toronto, Ontario.

BOWER, J. R., Assistant to Chief Electrician, Electrical Dept., American Car & Foundry Co., Berwick; res., Bloomsburg, Pa.

BRUNDAGE, DARIUS COLE, Plant Dept., Western Union Telegraph Co.; res., 403 W. 115th St., New York, N. Y.

BURGESON, ERNEST B., Central Palma, Palma Soriano, Oriente, Cuba.

*BUTZ, CHARLES HAROLD, Cadet Engineer, Denver Gas and Electric Light Co., Denver, Colo.

CLEMENTS, CHARLES JOSEPH, Engineering Dept., Cleveland Electric Illuminating Co., Illuminating Bldg., Cleveland, O.

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CLOKEY, ALLISON A., Engineering Assistant, Western Union Telegraph Co., 195 Broadway, New York, N. Y.

*CONNER, JOHN LAMBERT, Instructor, Electrical Engineering Dept., Lehigh University, So. Bethlehem; res., 818 Broad St., Quakertown, Pa.

COOKE, ROBERT F., Chief Electrician, Trinity Gold Dredging Co., Lewiston, Cal.

COREY, JAMES WILLIAM, Sales Engineer, Reliance Electric & Engineering Co., Cleveland, O.

*CREVELING, ALFRED BENJAMIN, Substation Operator, Pacific Power & Light Co.; res., 1014 University St., Walla Walla, Wash.

CREWSON, GEORGE GRANT, Mechanical Engineer, Roessler & Hasslacher Chemical Co., Perth Amboy, N. J.; res., 222 Wood Ave., Tottenville, N.Y.

DEPWEG, LEONARD S., Engineer, Induction Motor Dept., Bullock Works, Allis-Chalmers Mfg. Co., Norwood; res., 4342 Carthage Pike, St. Bernard. Ohio.

DISBROW, GEORGE GRANVILLE, General Foreman, Lynchburg Traction and Light Co.. Lynchburg, Va.

DIXON, JOSEPH L., Electric Furnace Engineer, John A. Crowley Co., 1222 Ford Bldg., Detroit, Mich.

ELLISON, LEWIS HALL, Engineer, Western Electric Co., Hawthorne Works; res., 3210 Arthington St.. Chicago, Ill.

EMMONS, OLIN JOSEPH, Wire Chief, Chicago Telephone Co.; res., 2030 Estes Ave., Chicago, Ill.

*ESPENSCHIED, FREDERIC F., Assistant Engineer, Hydro-Electric Power Commission; res., 16 Biggar Ave., Toronto, Ontario.

*FAIRBANK, PARKER WHEELER, Chief Engineer, Stanley Works; res., 5 Garden St., New Britain, Conn.

FANTOZZI, CONRAD TULLINS JOSEPH, Switchboard Repairman, Chicago Telephone Co.; Student, University of Chicago; res., 2144 Coulter St., Chicago, Ill.

FISCHER, ERNEST AUGUST, 305 West 118th St., New York, N. Y.

FITZ, ERNEST SHERMAN, Superintendent of Distribution, Blackstone Valley Gas & Electric Co., Pawtucket, R. I.

FOOTE, JAMES B., Chief Engineer, Consumers Power Co.; res., 729 W. Washington St., Jackson, Mich.

*FORSTER, F. T., Electrical Engineer, Lightning Arrester Dept., General Electric Co., Pittsfield, Mass.

FREEMAN, FREDERICK SLOCUMB, Superintendent of Power Operation, Boston Elevated Railway Co., 439 Albany St., Boston, Mass.

FUROKU, TOSAKU, Engineer-Lieutenant, Imperial Japanese Navy, Navy Department, Tokyo, Japan.

GARRETT, WILLIAM WALTON, JR., Electrical Laboratory, Electrical Engineering Dept., Tennessee Coal, Iron & Railroad Co., Ensley, Ala.

GOOCH, ERNEST C., Electrical Engineer, Industrial Control Dept., General Electric Co.; res., 164 Furman St., Schenectady, N. Y.

GORDON, MERRITT WILLIAM, Telephone Engineer (Plant), Glen Telephone Co.; res., 705 S. Perry St. Johnstown, N.Y.

GUILFORD, WILLIAM S., Town Electrical Engineer, Municipality of Boksburg, Transvaal, South Africa.

GUSTAFSON, RICHARD V., Inventory Field Clerk, Sanderson & Porter, Chicago; res., 4814 W. 23rd St., Cicero, Ill.

HADCOCK, JAMES PERRY, Engineering Dept., Canadian General Electric Co.; res., 646 George St., Peterboro, Canada.

*HAIGH, PAUL N., Inspector, Electrification Dept., C. M. & St. P. Ry. Co., Barberton, O.

HALE, GEORGE RAYMOND, 16 Old Harbor St., South Boston. Mass.

HAMMOND, HERBERT H., Sales Manager, Standard Electric Time Co., 261 Franklin St., Boston; res., 202 Webster St., Malden, Mass.

HARTMAN, LAMBERT JOSEPH, Engineer, Public Service Electric Co., Newark; res., 22 Bremond St., Belleville, N.J.

*HAVESON, HERMAN, Engineering and Contracting, 148 So. Broad St., Trenton, N. J.

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*HAYS, LOWELL K., Engineer, Penn Public Service Co., Clearfield, Pa.

HILL, FREDERICK WILLIAM LANDIS, Cadet Engineer, New York Edison Co.; res., 101 W. 74th St., New York, N. Y.

HINRICHS, ERNST, Master Mechanic and Chief Electrician, Commonwealth Mining & Milling Co., Pearce, Ariz.

JOHNSON, CHESTER ALBERT, Chief Electrician, El Paso Smelting Works, El Paso, Texas.

JONES, HUGH SHEPARD, Salesman, Robbins & Myers Co., San Francisco; res., 1632 Sonoma Ave., Berkeley, Cal.

*KENNEDY, OWEN W., Assistant Patent Attorney, Patent Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

KETCHUM, GEORGE COLVIN, Equipment Engineer, Western Electric Co., Hawthorne; res., 3210 Arthington St., Chicago, Ill.

KOHLOSS, F. HENRY, Electrician, Du Pont Powder Co., City Point; res., 204 N. Jefferson St., Petersburg, Va.

LEIBFRIED, WILLIAM, Electrical Engineer, Wm. Gordon Corp., New York, res., 97 Guernsey St., Brooklyn, N. Y.

LOWELL, ROBERT TRAILL SPENCE, Lieutenant, U.S. Navy, Navy Department, Washington, D. C.

MACKINTOSH, CHARLES, Control House Operator, Panama Canal, Pedro Miguel, Canal Zone.

MARTIN, HENRY, JR., Engineer, Research Laboratory, Western Electric Co., New York; res., 1187 Decatur St., Brooklyn, N. Y.

MATTHEWS, CAREY T., Bookkeeper, Wake Machine Works, Kennebec, N. C.

MATTHEWS, EDGAR MASSABEAU, Engineering Dept., American Telephone & Telegraph Co., 195 Broadway, New York, N. Y.

MCDONALD, D. W., Electrician, Panama Canal, Pedro Miguel, Canal Zone.

MEISSNER, EDWIN B., Assistant to President, St. Louis Car Co., 8000 No. Broadway, St. Louis, Mo.

MEYER, HERBERT W., Line Inspector, Minneapolis General Electric Co.; res., 743 N. E. Madison St., Minneapolis, Minn.

MISER, WALTER B., General Superintendent, Jacksonville Railway & Light Co., 224 South Main St.; res., 1063 W. College Ave., Jacksonville, Ill.

MOFFAT, DAVID H., Foreman, Electrical Division, Panama Canal, Balboa, Canal Zone.

NICHOLAS, FREDERIC, Contributing Editor, *Electrical World*, New York; res., Tanglewylde Ave., Bronxville, N. Y.

OLIVER, SAMUEL LOFTIN, Superintendent, Sampson Power Co., Clinton, N. C.

OSTERMANN, G. R., Foreman of Construction, O. & M. Dept., Pacific Gas & Electric Co., Woodland; res., Nevada City, Cal.

OWEN, CHARLES SUMNER, Engineer, Ohio State Telephone Co.; res., 1465 E. 94th St., Cleveland, Ohio.

PALMER, WALTER S., Assistant Engineer, Power Plant, Hawaiian Commercial & Sugar Co., Puunene, Maui, T. H.

PATTERSON, ROBERT F., Electrical Engineer, Pressed Steel Car Co., Pittsburgh, Pa., Western Steel Car & Foundry Co., Chicago, Ill.; res., 1226 Sixth Ave., Beaver Falls, Pa.

POLLOCK, ROBERT THOMAS, Vice-President and Works Manager, Stenotype Co.; res., 3055 North Meridian, Indianapolis, Ind.

PUPPE, FRED W., Electrical Engineer, Chile Exploration Co., Chuquicamata, Chile, South America.

PURTEE, LESTER GANES, Superintendent of Power and Shops, Oklahoma Railway Co.; res., 1107 W. 23rd St., Oklahoma City, Okla.

*READ, WILLIAM GEORGE, Assistant Engineer in charge of Telephone Dept., Public Utilities Commission, Topeka, Kans.

RICHARDSON, ALBERT N., General Superintendent, Kansas City Light & Power Co.; res., 3615 Tracy Ave., Kansas City, Mo.

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ROSS, EMMETT W., JR., Foreman, Electrical Dept., Remington Arms Co., Eddystone; res., 115 Jackson St., Collingdale, Pa.

RUTHERFURD, ROSCOE OLIVER, Apprentice Switchboard Man, Pacific Telephone & Telegraph Co.; res., 122 No. Hope St., Los Angeles, Cal.

RUTLEDGE, THOMAS WILLIAM, Inspector, Arthur G. McKee & Co., 1301 Rockefeller Bldg., Cleveland, Ohio.

SAXTON, CHARLES WARING, Electro-Mechanical Engineer, Wuihi Mining Co., Hora Hora, Piarere, Auckland, New Zealand.

*SCHULTZ, G. ELMORE, Sales Engineer, Westinghouse Electric & Mfg. Co., 165 Broadway, New York, N. Y.

SCOTT, HENRY MELBOURNE, Sales Engineer, Aluminum Co. of America, 2400 Oliver Bldg., Pittsburgh, Pa.

*SHAW, CARROLL HARPER, Electrical Engineer, Sheboygan Railway & Electric Co.; res., 1514 N. 7th St., Sheboygan, Wis.

SHEDD, MARTIN EDWARD, Switchboard Inspector, So. New England Telephone Co.; res., 6 Linden Parkway, Norwich, Conn.

SHEPARD, EDWARD MARTIN, JR., Member of firm, Little and Shepard, 2033 Dime Bank Bldg., Detroit, Mich.

STEIERT, RALPH B., Construction Foreman, Chanslor-Canfield Midway Oil Co., Fellows, Cal.

STOKES, STANLEY, Sales Engineer, Electric Co. of Missouri, Webster Groves; res., 936 Goodfellow Ave., St. Louis, Mo.

STONE, IRVING ORRISON, Assistant to Chief Engineer, Maine Public Utilities Commission, Augusta, Me.

SUMNER, CHARLES L., JR., Operating Dept., United Railroads; res., 791 San Jose Ave., San Francisco, Cal.

*TALLMADGE, EVERETT SPENCER, Cost Clerk, Electric Construction Co. 176 E. 6th St., St. Paul, Minn.

*TAYS, EUGENE, Operating and Maintenance Dept., Pacific Gas & Electric Co., Benicia, Cal.

*TEN HAAGEN, JEAN ETTIENE, Assistant Foreman, Construction Dept., Commonwealth Edison Co.; res., 3512 Wilton Ave., Chicago, Ill.

TUCK, FREDERICK WILLIAM, Electrician, Giant Powder Works, Giant P. O., C. C. Co., Cal.

VAN BERGEN, KENNETH BROWN, Draftsman, Electric Construction Co.; res., 880 Fairmount Ave., St. Paul, Minn.

WAGNER, CHARLES FRANCIS, Mechanical Engineer, J. B. McCrary Co., 1408 First National Bank Bldg., Atlanta, Ga.

WALLACE, EDWARD P., Electrolysis Engineer, Mo. & Kansas Tel. Co.; res., 3508 Wabash, Kansas City, Mo.

WEEKS, ROBERT WALCOTT, Assistant Engineer, Gibbs & Hill, Pennsylvania Station, New York, N. Y.

*WELLS, ARTHUR STANTON, Engineer with John A. Stevens, 8 Merrimack St., Lowell, Mass.

WHEELER, HARRY EDWARD, General Auditor, Texas Southern Electric Co., Room 333, 50 Congress St., Boston, Mass.

*WINNE, HARRY A., Engineer, Power and Mining Dept., General Electric Co.; res., 233 Union St., Schenectady, N. Y.

*WOODRUFF, W. WARREN, Assistant Engineer, Engineering Dept., E. I. du Pont de Nemours & Co., Wilmington, Del.; res., 103 Linwood Ave., Ardmore, Pa.

WYGOD-WYGODSKY, HENRY, Engineering Assistant, Port Morris Power Station, N.Y.C.R.R. Co.; res., 667 Crotona Park North, New York, N.Y.

YARRINGTON, CYRUS ALEXANDER, Industrial Engineer, Standard Electric & Elevator Co., 123 South Calvert St., Baltimore, Md.

Total 102.

*Former enrolled Students.

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APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before September 30, 1916.

Baruch, S. E. (Member), San Francisco, Cal.
Bear, S. L., East Pittsburgh, Pa.
Borger, J. J. (Member), Augusta, Ga.
Bowler, S. E., Hartford, Conn.
Corkran, J. G., Cristobal, C. Z.
Cox, W. N., Baltimore, Md.
deWyrall, O. E., New York, N. Y.
Ferguson, H. F., Pittsburgh, Pa.
Fernandez-Mareque, F., Asuncion, Paraguay.
Fisher, E. H., N. Braddock, Pa.
Floyd, F. N., Trinidad, Colo.
Franklin, C. W., New York, N. Y.
Gerend, M. S., Grafton, Cal.
Gilmour, A. D., Iquique, Chile
Gray, F. J., New York, N. Y.
Henry, L. W., Alcoa, Tenn.
Hoffmann, J. J., Milwaukee, Wis.
Honaman, R. K., Lancaster, Pa.
Jones, C. G., Bay City, Mich.
Komiya, J., Tokyo, Japan
Macloon, E. H., Groveton, N. H.
Mapes, M. C. (Member), New Haven, Conn.
McClure, D. C., Denver, Colo.
Metz, E. C., Washington, D. C.
Myshenkoff, C. S., Moscow, Russia
Neff, C. C., Neffs, O.
Nelson, A. L., Boston, Mass.
Oliver, A. D. (Member), Havana, Cuba
Parker, R. W., Belleville, Ill.
Regal, A. P., Akron, O.
Sage, R. S., Schenectady, N. Y.
Sand, J. H., New York, N. Y.
Shallcross, S. M., East Pittsburgh, Pa.
Simpson, F., Akron, O.
Stavely, E. B., Ampere, N. J.
Stearns, C. M., Boston, Mass.
Steiner, L. E., Toledo, O.
Stevens, R. P. (Member), Youngstown, O.
Swartz, T. W., Spokane, Wash.
Swift, F., Fort Wayne, Ind.
Taliaferro, T. C., Atlanta, Ga.
Thomas, J. E., Pittsburgh, Pa.
Wilkins, R., Sacramento, Cal.
Wilson, J. S., City Point, Va.
Wilson, R. M., Seattle, Wash.
Winkley, S. F. (Member), London, England
Wiseman, D. E., San Francisco, Cal.
Yambert, D. W., Toledo, O.

Total 48

STUDENTS ENROLLED AUGUST 8, 1916

8267 Redding, A. M., Univ, of Penna.
8268 Rau, C. A., Univ. of Wisconsin
8269 Black, T. A., Casino Technical Night School
8270 Nystrom, A. W., Casino Technical Night School
8271 Trostle, J. E., Jr., Casino Technical Night School
8272 Eisaman, J. R., Casino Technical Night School
8273 Paddock, L. M., Casino Technical Night School
8274 Dustan, F. S., Casino Technical Night School
8275 Muir, R., Casino Technical Night School
8276 Rukenbrod, J. K., Casino Technical Night School
8277 Leighner, W. J., Casino Technical Night School
8278 Kottman, H. W., Casino Technical Night School
8279 Coldwell, E. S., Mass. Inst. Tech.
8280 Kruse, R. H., Univ. of Cincinnati

Total 14

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ACCESSIONS TO LIBRARY

This list includes books on electrical subjects only, which have been added to the library of the A. I. E. E. and the U. E. S. during the past month, not including periodicals and other exchanges.

Tentative Standard for the Construction and Installation of Materials for Lightning Rod Equipments. Edition May, 1916. Gift of Underwriters' Laboratories)

Yearbook of Wireless Telegraphy and Telephony, 1916. London, The Wireless Press, 1916. (Gift of Marconi's Wireless Telegraph Co.)

UNITED ENGINEERING SOCIETY

Block Signal and Interlocking System of the subway division of the Interborough Rapid Transit Company. (Bulletin No. 21 Union Switch & Signal Company) (Gift Union Switch & Signal Company)

Principles of Electrical Design. D. C. and A. C. generators. By Alfred Still. New York, 1916. (Purchase)

Results of Magnetic Observations made by the United States Coast and Geodetic Survey in 1915. (U. S. Coast & Geodetic Survey Special Publication No. 36) Washington, 1916. (Purchase)

Results of Observations made at the United States Coast and Geodetic Survey Magnetic Observatory at Vieques, Porto Rico, 1913-1914. (U. S. Coast & Geodetic Survey, Serial No. 33) Washington, 1916. (Purchase)

Theory and Calculation of Alternating-Current Phenomena. Ed. 5. By C. P. Steinmetz. New York, 1916. (Purchase)

Wireless Telegraphy. By J. Zenneck. New York 1915. (Purchase)

Zircon, Monazite and other minerals used in the production of chemical compounds employed in the manufacture of lighting apparatus. (Bulletin No. 25, North Carolina Geological & Economic Survey) Raleigh, 1916. (Purchase)

EMPLOYMENT DEPARTMENT

Note: Under this heading brief announcements (not more than fifty words in length) of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months: during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

VACANCIES

V-158. Electrochemical Engineer. College graduate with several years' experience. Knowledge of electrical welding, brass and zinc plating, substation, lights, motors, transformers, laboratory experience, also general plant maintenance, etc., desirable. Answer to include age, experience, history of employment and salary expected.

V-159. Graduate electrical engineer, preferably with one or two years' experience, for sales department of company devoting its energies to the manufacture of alternating-current apparatus. Correspondence confidential; give all particulars.

V-160. Superintendent and Chief Engineer for a Diesel engine central station of two 500-h.p. units, in a western state; elevation five thousand. Must be responsible, efficient superintendent and competent, workmanlike chief, with some experience with Diesel engines.

V-161. Electrical Laboratory Instructor wanted by technical school in Brooklyn. Practical and teaching experience necessary and must be graduate of engineering school. Beginning salary about $1500, depending on individual. Apply by letter giving age, full details of experience and education, and recent photograph, if possible.

V-163. Electrical Engineer, to take charge of department for prominent firm of consulting engineers; familiar with hydroelectric high-voltage design and construction; one who is competent to lay out, prepare plans and specifications therefor, and design the electrical features in connection with hydroelectric power plants, including transmission and substation equipment. Must be qualified to take full charge of electrical work of this nature.

V-164. Wanted: Transformer Engineer for service in London. Details will be furnished upon application.

V-165. Wanted. Operating man with experience to take charge of steam

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turbines and substation plants with capacity of 15,000 kw. Apply to H. E. Shedd, Appalachian Power Company, Bluefield, W. Va.

V-166. Industrial concern with headquarters in New York, seeks electrical engineer with experience in a.c. and d.c. and proficient in general electrical work. Must be good draftsman and be able to calculate size and type of equipment required. Salary $25 to $30 per week.

V-167. Wanted. Two technical graduates who have had some experience, to act as instructors in a school of electrical engineering, preferably men with experience in telephone or telegraph work. Moderate salary

V-168. New Business man required by Western power company. Must be well informed on the application of electricity in coal mining: conduct necessary tests and make out convincing reports for securing this class of business. Please give full information as to training and experience.

MEN AVAILABLE

540. Electrical Engineer, now employed by the government in Southwest, desires change. Twelve years' experience in designing, windings of all kinds, station, wiring inside and outside, all kinds of automobile work, telephones, radio, consulting electrical engineering, drafting, Speaks French and Spanish. Salary secondary to permanence and future prospects of the position. Will go anywhere.

541. High School graduate, student New York Electrical School, evening course, age 19, no electrical experience, wishes employment to learn electrical business. At present in stock-brokerage office.

542. Executive, Mechanical-Electrical Engineer, Mem. both societies, age 41. Superintendent of operation largest city systems, East; 18 years' responsibility, design, construction, operation. Successful organizer. Main and substation economies, boilers, stokers, smoke abatement, transmission, distribution, energy, supply to railways. Best recommendations from employing corporations. Desires position in executive or semi-executive capacity.

543. Position wanted, preferably in vicinity of New York, as works manager, or officer in manufacturing company Engineering graduate with considerable experience here and abroad, in large electrical company. Familiar with economical shop methods involving labor and material, and successful handling of employes.

544. University graduate, age 28, desires position as assistant electrical engineer with railway, consulting, operating, or construction company. Four years' experience in drafting and designing of high-tension transmission systems power plants, substations, switching equipments, light and power installations, etc. At present employed.

545. Assistant to Manager or Executive, by young man of twenty-five with good education. At present connected with mercantile business as manager.

546. Electrical Engineer, married, reliable and competent, wishes position with engineer, central station, or industrial plant. Twenty years' experience in design, construction, operation and repairs, including armature winding. Can do drafting; is familiar with steam and also experienced in storage battery work with attendant starting, lighting and ignition troubles. Thoroughly acclimated in South.

547. Electrical Engineer, technical graduate, seven years' experience with General Electric Co., including laboratory, testing, design, and office work; also three years' construction and operating experience in Canada, the U. S. and Cuba. Age 34; single.

548. Electrical Engineer. Technical education, thorough training, theoretical and practical, in operation and design of electrical power installations. Seven years with Westinghouse Co. Four years as electrical engineer for prominent firm of consulting industrial engineers. Can accept position of responsibility on short notice.

549. Technical graduate, age 22, desires position with consulting engineer. Very good in all branches of mathematics. At present employed.

550. Engineer with exceptional inventive talent wants a position requiring such ability. Cornell graduate, M. E. degree (specialized in E. E.), with M. S. degree from Union College. One year testing at General Electric and two years as university instructor in electrical engineering. At present assistant engineer of a chemical factory.

551. Electrical Engineer, Columbia graduate (1906), age 33, single, with ten years' experience specifying, purchasing, testing and designing installations of generating and substation electrical apparatus for a large light and power company. At present employed; desires position with consulting

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engineer or as assistant engineer of electrical power company.

552. Cables.—Young man, technical training, single, familiar with cables and cable work from manufacture through testing to installation; both telephone and power; also conduit work, seeks connection, either directly in the line or relative to it. Also some sales experience. Moderate salary if prospects are good.

553. The services of an energetic and capable engineer, age 32, available on short notice. Ten years' experience in industrial motor applications, central station construction and operation, and as manager of light and water systems. Technical graduate. Will consider any opening of good future prospects. Could make moderate investment.

554. Mechanical and Electrical graduate, 30 years old, clean character, industrious; now employed, desires position as assistant to executive. Eight years' experience directing drafting, testing, inspecting, and in factory operation. Accustomed to traveling and meeting customers, salesmen, etc. Has knowledge of purchasing; salary $160.

555. Steam and Electrical Engineer, Mem. A. I. E. E., desires position. Over twenty years' experience, chiefly in electric railway field. Has specialized in power station construction, equipment and operation and overhead line construction and maintenance. Willing to go anywhere. Correspondence solicited.

556. Chief Electrician and Electrical Engineer of twenty years' experience in the electrical field; installation and maintenance. Motors, generators, substation, storage batteries, telephones—regular and automatic. Can handle men and get results. Age 39; good record. Ten years with one company. Business experience.

557. Graduate applied electricity course, Wentworth Institute, desires position as switchboard operator; place and hours convenient to preparatory school and college. Age 19. Can go anywhere in the East. Any position permitting working way through college considered. Now employed as operator.

558. Practical Engineer, technical graduate and Westinghouse apprenticeship course, with three years' shop, one year power house, one year testing, and three years' office and two years' sales experience, wants employment with utility company or sales engineering work, with chance to advance. Age 29; good habits; salary $1500.

559. Efficiency Engineer, desires permanent position with central station operating company. Technical graduate, well known as writer on technical subjects. Two years machinist's apprentice; one year in bank; four years as construction engineer; one year on appraisal work; four years on central station work; has first-class assistant chief engineer's license. Minimum salary $2400.

560. Electrical Engineer, technical graduate, age 40. Eight years' miscellaneous shop experience; ten years' experience in operation, maintenance and installation of steam plants and substations; desires position. Will accept moderate salary with company where ability will lead to advancement. At present employed.

561. Public Utility Manager, holding good position, wishes Eastern location. A. I. E. E. and N. E. L. A. Extensive experience. Commercial engineer on large light and power propositions. Electrical Engineer on design, construction, operation of overhead and underground transmission, distribution and generating systems. Reorganization of run-down utilities and management of traction and power properties.

562. Electrical Engineer, thirty years of age, having had eight years' practical experience, is open for position about October 1. Experienced in the design construction and operation of hydro-electric plants, transmission systems, railway work. Technical graduate. Now acting as electrical engineer for 1500-volt d-c. interurban road.

563. Graduate Electrical Engineer. Mem. A. I. E. E. and I. E. S. Twenty years' experience in engineering, construction and executive work in telephone, electric light, power wiring, and equipment; just completing reorganization of manufacturing plant; desires to associate himself with large growing company, either in reorganization work or in executive position.

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OFFICERS AND BOARD OF DIRECTORS, 1916-1917.

PRESIDENT.
(Term expires July 31, 1917)
H. W. BUCK

JUNIOR PAST-PRESIDENTS.

(Term expires July 31, 1917)	(Term expires July 31, 1918)
PAUL M. LINCOLN	JOHN J. CARTY

VICE-PRESIDENTS.

(Term expires July 31, 1917)	(Term expires July 31, 1918)
C. A. ADAMS	B. A. BEHREND
J. FRANKLIN STEVENS	P. JUNKERSFELD
WILLIAM McCLELLAN	L. T. ROBINSON

MANAGERS.

(Term expires July 31, 1917)	(Term expires July 31, 1918)	(Term expires July 31, 1919)
FREDERICK BEDELL	C. E. SKINNER	CHARLES S. RUFFNER
BANCROFT GHERARDI	F. B. JEWETT	JOHN B. FISKEN
A. S. McALLISTER	JOHN B. TAYLOR	CHARLES ROBBINS
JOHN H. FINNEY	HAROLD PENDER	N. A. CARLE

TREASURER (Term expires July 31, 1917) **SECRETARY.**
GEORGE A. HAMILTON F. L. HUTCHINSON

HONORARY SECRETARY.
RALPH W. POPE

LIBRARIAN.
W. P. CUTTER

GENERAL COUNSEL.
PARKER and AARON,
52 Broadway, New York.

PAST PRESIDENTS.—1884-1916.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMPSON, 1889-90
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-92
FRANK JULIAN SPRAGUE, 1892-3.
*EDWIN J. HOUSTON, 1893-4-5.
*LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-02
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4
JOHN W. LIEB, 1904-5
SCHUYLER SKAATS WHEELER, 1905-6
SAMUEL SHELDON, 1906-7.
HENRY G. STOTT, 1907-8
LOUIS A. FERGUSON, 1908-09.
LEWIS B. STILLWELL, 1909-10.
DUGALD C. JACKSON, 1911-10.
GANO DUNN, 1911-12.
RALPH D. MERSHON, 1912-13.
C. O. MAILLOUX, 1913-14.
PAUL M. LINCOLN, 1914-15.
JOHN J. CARTY, 1915-16.

*Deceased.

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INSTITUTE COMMITTEES.

Revised to September 1, 1916.

GENERAL STANDING COMMITTEES.

EXECUTIVE COMMITTEE.

H. W. Buck, Chairman,
49 Wall Street, New York.
N. A. Carle, George A. Hamilton,
John H. Finney, William McClellan,
Bancroft Gherardi, J. Franklin Stevens.

FINANCE COMMITTEE.

J. Franklin Stevens, Chairman,
1326 Chestnut Street, Philadelphia, Pa.
N. A. Carle, Bancroft Gherardi.

MEETINGS AND PAPERS COMMITTEE.

L. T. Robinson, Chairman,
General Electric Company, Schenectady, N.Y.
Frederick Bedell, L. W. Chubb,
Harris J. Ryan, Charles P. Steinmetz,
and the chairmen of the Technical Committees.

EDITING COMMITTEE.

W. I. Slichter, Chairman,
Columbia University, New York.
Frederick Bedell, L. T. Robinson,
M. G. Lloyd, C. E. Skinner.

CODE COMMITTEE.

Farley Osgood, Chairman.
763 Broad Street, Newark, N. J.
J. C. Forsyth, H. R. Sargent,
H. B. Gear, G. A. Sawin,
A. H. Griswold, A. M. Schoen,
H. O. Lacount, George F. Sever,
Johnston Livingston, C. E. Skinner,
H. S. Warren.

BOARD OF EXAMINERS.

A. S. McAllister, Chairman,
Engineers' Club, 32 West 40th Street,
New York.
E. B. Katte, W. I. Slichter,
F. L. Rhodes, Philip Torchio.

SECTIONS COMMITTEE.

W. A. Hall, Chairman,
General Electric Company, West Lynn, Mass.
J. G. De Remer, A. M. Schoen,
Paul M. Lincoln, J. H. Tracy,
and the chairmen of all Institute Sections,
ex-officio.

PUBLIC POLICY COMMITTEE.

Calvert Townley, Chairman,
165 Broadway, New York.
E. A. Carolan, William McClellan,
John J. Carty, H. H. Porter,
Fredk. Darlington, C. S. Ruffner,
Gano Dunn, A. M. Schoen,
John B. Fisken, L. B. Stillwell,
A. M. Hunt, H. G. Stott.

STANDARDS COMMITTEE.

C. A. Adams, Chairman,
Harvard University, Cambridge, Mass.
Harold Pender, Secretary,
University of Pennsylvania, Philadelphia, Pa.
P. G. Agnew, P. Junkersfeld,
Frederick Bedell, A. E. Kennelly,
L. F. Blume, G. L. Knight,
James Burke, A. S. McAllister,
G. A. Burnham, W. M. McConahey,
N. A. Carle, W. L. Merrill,
E. J. Cheney, Charles Robbins,
E. H. Colpitts, L. T. Robinson,
F. P. Cox, C. H. Sharp,
W. A. Del Mar, C. E. Skinner,
E. J. Edwards, A. J. Slade,
H. W. Fisher, N. W. Storer,
H. M. Hobart, H. G. Stott,
H. D. James, R. B. Williamson.

COMMITTEE ON DEVELOPMENT OF WATER POWER.

John H. Finney, Chairman,
509 Metropolitan Bank Building, Washington, D. C.
F. O. Blackwell, E. A. Lof,
Francis Blossom, W. V. N. Powelson,
Gano Dunn, L. B. Stillwell,
Nicholas S. Hill, Jr., H. G. Stott.

UNITED STATES NATIONAL COMMITTEE OF THE INTERNATIONAL ELECTROTECHNICAL COMMISSION.

C. O. Mailloux, President,
20 Nassau Street, New York.
F. B. Crocker, Vice-President,
A. E. Kennelly, Secretary,
Harvard University, Cambridge, Mass.
C. A. Adams, E. B. Rosa,
B. A. Behrend, Charles F. Scott,
Louis Bell, Clayton H. Sharp,
James Burke, Samuel Sheldon,
John J. Carty, C. E. Skinner,
Gano Dunn, Charles P. Steinmetz,
H. M. Hobart, H. G. Stott,
John W. Lieb, Elihu Thomson,
R. B. Owens, Philip Torchio.
M. I. Pupin,

PATENT COMMITTEE.

Ralph D. Mershon, Chairman,
80 Maiden Lane, New York.
Bion J. Arnold, Charles A. Terry,
John F. Kelly, B. F. Wood.

EDISON MEDAL COMMITTEE.

Appointed by the President for terms of five years.

Term expires July 31, 1917.
A. E. Kennelly, Robert T. Lozier,
S. G. McMeen.

Term expires July 31, 1918.
H. W. Buck, F. A. Scheffler,
J. Franklin Stevens.

Term expires July 31, 1919.
Charles P. Brush N. W. Storer

Term expires July 31, 1920.
Carl Hering Harris J. Ryan
H. G. Stott.

Term expires July 31, 1921.
(Not yet appointed

Elected by the Board of Directors from its own membership for terms of two years.

Term expires July 31, 1917.
B. A. Behrend, Paul M. Lincoln,
William McClellan.

Term expires July 31, 1918.
C. A. Adams, Harold Pender,
C. E. Skinner.

Ex-Officio.

H. W. Buck, President,
George A. Hamilton, Treasurer,
F. L. Hutchinson, Secretary.

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TECHNICAL COMMITTEES.

Revised to September 1, 1916.

POWER STATIONS.

J. G. De Remer, Chairman,
100 Broadway, New York.

J. M. Drabelle,
C. C. Egbert,
W. S. Gorsuch,
John Harisberger,
A. H. Kruesi,
Paul M. Lincoln,
Wynn Meredith,
I. E. Moultrop,
S. A. Moss,
R. J. S. Pigott,
Cecil Poole,
E. F. Scattergood,
F. A. Scheffler,
H. G. Stott,
W. R. Thompson,
Philip Torchio,
H. L. Wallau,
B. F. Wood.

TRANSMISSION AND DISTRIBUTION.

L. E. Imlay, Chairman,
Niagara Falls Power Co., Niagara Falls, N. Y.

H. A. Barre,
M. T. Crawford,
E. E. F. Creighton,
H. H. Dewey,
P. M. Downing,
H. W. Fisher,
F. A. Gaby,
W. T. Goddard,
O. A. Havill,
R. F. Hayward,
J. P. Jollyman,
P. M. Lincoln,
W. E. Mitchell,
G. J. Newton,
L. C. Nicholson,
Stefaan Piek,
C. S. Ruffner,
H. J. Ryan,
F. D. Sampson,
H. E. Shedd,
Julian C. Smith,
P. H. Thomas.

TRACTION AND TRANSPORTATION.

N. W. Storer, Chairman,
Westinghouse E. & M. Co., East Pittsburgh, Pa.

Harry H. Adams,
A. H. Babcock,
Reinier Beeuwkes,
E. J. Blair,
L. P. Crecelius,
J. V. B. Duer,
George Gibbs,
W. J. Harvie,
Hugh Hazelton,
E. B. Katte,
P. J. Kearny,
William McClellan,
John Murphy,
W. B. Potter,
E. D. Priest,
Charles H. Quinn,
Clarence Renshaw,
A. S. Richey,
Charles F. Scott,
John B. Taylor,
H. S. Warren.

COMMITTEE ON ELECTRICITY FOR INDUSTRIAL AND DOMESTIC USE.

E. H. Martindale, Chairman,
National Carbon Co., Cleveland, Ohio.

J. H. Davis,
A. M. Dudley,
Herbert B. Dwight,
F. W. Ells,
J. E. Fries,
F. R. Fishback,
R. H. Goodwillie,
A. L. Hadley,
G. A. Johnstone,
C. A. Kelsey,
C. L. Kennedy,
Charles D. Knight,
A. H. Lawton,
A. M. MacCutcheon,
A. G. Pierce,
James M. Smith,
H. Weichsel,
J. B. Wiard,
R. B. Williamson.

LIGHTING AND ILLUMINATION.

Edward P. Hyde, Chairman,
Nela Park, Cleveland, O.

G. M. Chamberlin,
C. E. Clewell,
J. R. Cravath,
T. S. Perkins,
Richard C. Powell,
E. B. Rosa,
W. D'A. Ryan,
Clayton H. Sharp,
W. M. Skiff.

COMMITTEE ON ECONOMICS OF ELECTRIC SERVICE.

(Not yet appointed.)

PROTECTIVE DEVICES.

D. W. Roper, Chairman,
Room 500, 72 W. Adams St., Chicago, Ill.

L. L. Elden,
G. Faccioli,
V. E. Goodwin,
E. M. Hewlett,
Paul M. Lincoln.
A. A. Meyer,
L. C. Nicholson,
N. L. Pollard,
S. D. Sprong,
Philip Torchio,
H. R. Woodrow.

ELECTROCHEMISTRY AND ELECTROMETALLURGY.

(Not yet appointed.)

TELEGRAPHY AND TELEPHONY.

F. L. Rhodes, Chairman,
15 Dey St., New York.

E. F. W. Alexanderson,
R. E. Chetwood,
M. M. Davis,
C. L. Fortescue,
H. M. Friendly,
F. B. Jewett,
S. M. Kintner,
Wm. Maver, Jr.,
Kempster B. Miller,
H. Mouradian,
W. O. Pennell,
Allard Smith,
John S. Stone,
John B. Taylor,
J. L. Wayne, 3rd,
G. M. Yorke.

USE OF ELECTRICITY IN MARINE WORK.

H. A. Horner, Chairman,
Hamilton Court, 39th & Chestnut Sts., Philadelphia, Pa.

R. B. Chillas, Jr.,
M. W. Day,
G. E. Edgar,
W. L. R. Emmet,
W. R. Furlong,
H. L. Hibbard,
Guy Hill,
O. P. Loomis,
D. M. Mahood,
G. A. Pierce, Jr.,
H. M. Southgate,
E. A. Sperry,
Wilfred Sykes,
F. W. Wood.

USE OF ELECTRICITY IN MINES.

(Not yet appointed.)

IRON AND STEEL INDUSTRY.

(Not yet appointed.)

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SPECIAL COMMITTEES.

Revised to September 1, 1916.

REORGANIZATION OF TECHNICAL COMMITTEES.

L. T. Robinson, Chairman,
General Electric Company, Schenectady, N. Y.
F. L. Hutchinson, H. H. Norris,
A. S. McAllister, J. Franklin Stevens,
N. W. Storer.

PROPOSED RESERVE CORPS OF ENGINEERS.

Bion J. Arnold, Chairman,
105 South La Salle Street, Chicago, Ill.
John Harisberger, A. M. Schoen,
Ralph D. Mershon, Charles W. Stone.

INSTITUTE REPRESENTATIVES.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

Ralph D. Mershon, Paul M. Lincoln,
C. O. Mailloux, John J. Carty,

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

H. H. Barnes, Jr., Gano Dunn,
Samuel Sheldon.

ON LIBRARY BOARD OF UNITED ENGINEERING SOCIETY.

Samuel Sheldon, Harold Pender,
Edward D. Adams, W. I. Slichter,
F. L. Hutchinson.

ON ELECTRICAL COMMITTEE OF NATIONAL FIRE PROTECTION ASSOCIATION.

The chairman of the Institute's Code Committee.

ON ADVISORY BOARD OF AMERICAN YEAR-BOOK.

Edward Caldwell.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

W. S. Franklin, G. W. Pierce.

ON CONFERENCE COMMITTEE OF NATIONAL ENGINEERING SOCIETIES.

Calvert Townley, William McClellan,
John J. Carty.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

Charles F. Scott, Samuel Sheldon.

ON NATIONAL JOINT COMMITTEE ON OVERHEAD AND UNDERGROUND LINE CONSTRUCTION.

Farley Osgood, F. B. H. Paine,
Percy H. Thomas.

ON JOINT NATIONAL COMMITTEE ON ELECTROLYSIS.

Bion J. Arnold, F. N. Waterman,
Paul Winsor.

ON U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ILLUMINATION COMMISSION.

A. E. Kennelly, C. O. Mailloux,
Clayton H. Sharp.

ON JOINT COMMITTEE ON CLASSIFICATION OF TECHNICAL LITERATURE.

F. B. Jewett.

ON ENGINEERING FOUNDATION BOARD.

Michael I. Pupin.

ON NAVAL CONSULTING BOARD.

Benjamin G. Lamme, Frank J. Sprague.

ON PAN-AMERICAN ENGINEERING COMMITTEE.

Gano Dunn, William McClellan,
John H. Finney, Charles W. Stone.
Calvert Townley.

LOCAL HONORARY SECRETARIES.

Guilo Semenza, N. 10 Via S. Radegonda, Milan, Italy.
Robert Julian Scott, Christchurch, New Zealand.
T. P. Strickland, N. S. W. Government Railways, Sydney, N. S. W.
W. G. T. Goodman, Adelaide, South Australia.
James S. Fitzmaurice, Perth, West Australia.
L. A. Herdt, McGill Univ., Montreal, Que.
Henry Graftio, Petrograd, Russia.
Richard O. Heinrich, Genest-str. 5, Schoeneberg, Berlin, Germany.
A. S. Garfield, 45 Boulevard Beausejour Paris, 16 E., France.
Harry Parker Gibbs, Tata Hydroelectric Power Supply Co., Ltd., Bombay, India.
John W. Kirkland, Johannesburg, South Africa.

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LIST OF SECTIONS

Revised to September 1, 1916.

Name and when Organized	Chairman	Secretary
Atlanta.....Jan. 19, '04	A. M. Schoen	H.E.Bussey,3d Nat. Bk. Bldg. Atlanta,Ga.
Baltimore.....Dec. 16, '04	J. B. Whitehead	L.M.Potts,Industrial Bldg.,Baltimore,Md.
Boston.....Feb. 13, '03	Geo. A. Burnham	Ira M.Cushing,84 State St.,Boston,Mass.
Chicago.....1893	Taliaferro Milton	W. J. Crumpton, 111 W. Monroe St. Chicago, Ill.
Cleveland.....Sept. 27, '07	E. W. P. Smith	Bruce W. David, Lincoln Electric Co., Cleveland, Ohio.
Denver.....May 18, '15	H. S. Sands	Robert B. Bonney, Mountain States Tel. and Tel. Co., Denver, Colo.
Detroit-Ann Arbor.....Jan. 13, '11	A. A. Meyer	A. Oakes, American Electrical Heater Company, Detroit, Mich.
Fort Wayne.....Aug. 14, '08	J. J. Kline	
Indianapolis-Lafayette..Jan. 12, '12	J. L. Wayne, 3rd	Walter A. Black, 3042 Graceland Ave., Indianapolis, Ind.
Ithaca.....Oct. 15, '02	E. L. Nichols	W. G. Catlin, Cornell Univ., Ithaca, N. Y.
Kansas City, Mo......Apr. 14, '16	Gordon Weaver	Glenn O. Brown, Kansas City Elec. Lt. Co., Kansas City, Mo.
Los Angeles.....May 19, '08	E. Woodbury	R. H. Manahan, 32 City Hall, Los Angeles, Cal.
Lynn.....Aug. 22, '11	Gordon Campbell	M. B. Carroll, Gen. Elec. Co., West Lynn, Mass.
Madison.....Jan. 8, '09	F. A. Kartak	L. E. A. Kelso, University of Wisconsin, Madison, Wis.
Mexico.....Dec. 13, '07		
Milwaukee.....Feb. 11, '10	F. W. Ells	H. P. Reed, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.....Apr. 7, '02	R. A. Lundquist	Vernon S. Beck, Beck Elec. Const. Co., Minneapolis, Minn.
Panama.....Oct. 10, '13	Earl J. Atkisson	C. W. Markham, Balboa Heights, C. Z.
Philadelphia.....Feb. 18, '03	H. P. Liversidge	W. F. James, 14th Floor, Widener Bldg., Philadelphia, Pa.
Pittsburgh.....Oct. 13, '02	G. C. Hecker	F. E. Wynne, W. E. and M. Company, East Pittsburgh, Pa.
Pittsfield.....Mar. 25, '04	V. E. Goodwin	E. K. Shelton, General Electric Company, Pittsfield, Mass.
Portland, Ore......May 18, '09	Paul Lebenbaum	L. T. Merwin, Northwestern Electric Co., Portland, Ore.
Rochester.....Oct. 9, '14	O. W. Bodler	Lucien Buck, 1416 Lake Avenue, Rochester N. Y.
St. Louis.....Jan. 14, '03	W. O. Pennell	George McD. Johns, Room 401, City Hall, St. Louis, Mo.
San Francisco.....Dec. 23, '04	J. E. Woodbridge	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
Schenectady.....Jan. 26, '03	C. E. Eveleth	H. L. Andrews, General Electric Company, Schenectady, N. Y.
Seattle.....Jan. 19, '04	C. E. Magnusson	C. F. Terrell, Puget Sound Trac. Lt. and Power Co., Seattle, Wash.
Spokane.....Feb. 14, '13	D. F. Henderson	C. M. Fisher, Washington Water Power Company, Spokane, Wash.
Toledo.....June 3, '07	W. E. Richards	Max Neuber, Cohen, Freidlander & Martin, Toledo, Ohio.
Toronto.....Sept. 30, '03	E. T. J. Brandon	Wills Maclachlan, 910 Excelsior Life Building, Toronto, Ont.
Urbana.....Nov. 25, '02	I. W. Fisk.	L. V. James, Univ. of Illinois, Urbana, Ill.
Vancouver.....Aug. 22, '11	R. F. Hayward	T. H Crosby, Canadian Westinghouse Co., Vancouver, B. C.
Washington, D.C......Apr. 9, '03	Arthur Dunlop	Louis G. Freeman, U. S. Geological Survey, Washington, D. C.

Total 33

LIST OF BRANCHES

Name and when Organized	Chairman	Secretary
Agricultural and Mech. College of Texas.....Nov. 12, '09	A. Dickie	G. B. Hanson.
Alabama, Univ. of.....Dec. 11, '14	Gustav Wittig	A. F. Frazier, University, Ala.
Arkansas, Univ. of.....Mar. 25, '04	A. L. Wilson	W. L. Teague, University of Arkansas, Fayetteville, Ark.
Armour Institute.....Feb. 26, '04	Ralph H. Earle	Harold A. Kleinman, 7743 Burnham Avenue, Chicago, Ill.
Brooklyn Poly. Inst......Jan. 14, '16	Albert H. Bernhard	Walter J. Seeley, The Polytechnic Institute, Brooklyn, N. Y.
Bucknell University....May 17, '10	N. J. Rehman	E. C. Hageman, Bucknell University, Lewisburg, Pa.
California, Univ. of.....Feb. 9, '12	Marc Holzer	C. Maynard, University of California, Berkeley, Cal.
Carnegie Inst. of Tech..May 18, '15	D. L. Trautman	D. F. Gibson, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of.....Apr. 10, '08	C. A. Powell	N. V. McCormick, 3110 Woodburn Ave., Cincinnati, Ohio.
Clarkson Col. of Tech...Dec. 10, '15	W. A. Dart	C. J. Dresser, Clarkson College of Technology, Potsdam, N. Y.
Clemson Agricultural Col. Nov. 8, '12	D. H. Banks	W. H. Neil, Clemson College, S. C.
Colorado State Agricultural College.....Feb. 11, '10	George L. Paxton	Charles F. Shipman, Colorado State Agricultural College, Fort Collins, Colo.

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LIST OF BRANCHES—Continued.

Name and when Organized	Chairman	Secretary
Colorado, Univ. of.....Dec. 16, '04	Charles C. Clymer	Victor E. Leroy, University of Colorado, Boulder, Colo.
Georgia School of Technology.....June 25, '14	C. R. Brown	J. E. Thompson, Georgia School of Technology, Atlanta, Ga.
Highland Park College..Oct. 11, '12	Carl Von Lindeman	C. F. Wright, Highland Park College, Des Moines, Iowa.
Idaho, Univ. of.....June 25, '14	E. R. Hawkins	C. L. Rea, Univ. of Idaho, Moscow, Idaho.
Iowa State College.....Apr. 15, '03	F. H. Hollister	F. A. Robbins, Iowa St. Col., Ames, Iowa.
Iowa, Univ. of.....May 18, '09	H. W. Matson	A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col...Jan. 10, '08	Walter E. Deal	G. B. McNair, Kansas State Agri. Col., Manhattan, Kansas.
Kansas, Univ. of.....Mar. 18, '08	N. M. Foster	G. M. Bowman, University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. of Oct. 14, '10	H. E. Melton	Margaret Ingels, 251 Delmar Avenue, Lexington, Ky.
Lafayette College.....Apr. 5, '12	Samuel McC. Hunt	Carl Theodore Mack, 418 McCartney Street, Easton, Pa.
Lehigh University.....Oct. 15, '02	F. L. Magee	J. F. Wentz, Lehigh University, South Bethlehem, Pa.
Lewis Institute.....Nov. 8, '07	P. B. Woodworth	G. K. Wadlin, Lambda Chi Alpha House, Orono, Maine.
Maine, Univ. of.....Dec. 26, '06	Fred P. Jones	F. E. Richardson, University of Michigan, Ann Arbor, Mich.
Michigan, Univ. of.....Mar. 25, '04	A. N. Clarke	Donald P. Loye, 4216 Dupont Ave., South Minneapolis, Minn.
Minnesota, Univ. of....May 16, '16	Jesse L. Thompson	A. C. Lanier, University of Missouri, Columbia, Mo.
Missouri Univ. of.....Jan. 10, '03	K. Atkinson	J. A. Thaler, Montana State College, Bozeman, Mont.
Montana State Col.....May 21, '07	Taylor Lescher	V. L. Hollister, Station A., Lincoln, Nebr.
Nebraska, Univ. of.....Apr. 10, '08	Olin J. Ferguson	R. L. Kelly, West Raleigh, N. C.
North Carolina Col. of Agr., and Mech. Arts.....Feb. 11, '10	R. V. Davis	W. H. Joyner, Univ. of North Carolina, Chapel Hill, N. C.
North Carolina, Univ. of.Oct. 9, '14	Edw. Y. Keesler	
Norwich University.....June 28, '16	H. H. Robinson	L. W. Birch, 138 Wheatland Avenue, Columbus, Ohio.
Ohio Northern Univ.....Feb. 9, '12	H. D. Bender	D. A. Dickey, Ohio State University, Columbus, Ohio.
Ohio State University....Dec. 20, '02		W. C. Lane, Oklahoma A. and M. College, Stillwater, Okla.
Oklahoma Agricultural and Mech. Col.....Oct. 13, '11	G. E. Davis	R. E. Heffner, University of Oklahoma, Norman, Okla.
Oklahoma, Univ. of.....Oct. 11, '12	H. M. Richards	J. A. Hooper, Oregon Agri. College, Corvallis, Ore.
Oregon Agr. Col.....Mar. 24, '08	Winfield Eckley	August Heine, State College, Pa.
Penn. State College.....Dec. 20, '02	G. Geracimos	W. K. Benz, University of Pittsburgh, Pittsburgh, Pa.
Pittsburgh, Univ. of.....Feb. 26, '14	G. R. Patterson	A. N. Topping, Purdue Univ., Lafayette, Indiana.
Purdue University.....Jan. 26, '03	C. F. Harding	W. R. Townsend, Jr., Rensselaer Polytechnic Institute, Troy, N. Y.
Rensselaer Poly. Inst...Nov. 12, '09	W. J. Williams	Sam P. Stone, 1012 North 8th Street, Terre Haute, Ind.
Rose Polytechnic Inst...Nov. 10, '11	H. E. Smock	Frank A. Faron, Rhode Island State College, Kingston, R. I.
Rhode Island State Col.Mar. 14, '13	C. E. Seifert	J. A. Shepard, Stanford University, Cal.
Stanford Univ.....Dec. 13, '07	H. J. Rathbun	R. A. Porter, Syracuse University, Syracuse, N. Y.
Syracuse Univ.....Feb. 24, '05	W. P. Graham	J. A. Correll, Univ. of Texas, Austin, Tex.
Texas, Univ. of.....Feb. 14, '08	J. M. Bryant	K. W. Rich, Throop College of Technology, Pasadena, Cal.
Throop College of Technology.....Oct. 14, '10	J. W. DuMond	John D. Hindle, Virginia Polytechnic Institute, Blacksburg, Va.
Virginia Polytechnic Institute.....Jan. 8, '15	V. Dixon	J. H. Moore, Dawsons Row, University, Va.
Virginia, Univ. of.....Feb. 9, '12	W. S. Rodman	H. V. Carpenter, State Col. of Wash., Pullman, Wash.
Wash, State Col. of.....Dec. 13, '07	M. K. Akers	R. W. Macdonald, Washington University, St. Louis, Mo.
Washington Univ.....Feb. 6, '04	Charles A. Lieber	J. R. Himmelsbach, University of Washington, Seattle, Wash.
Washington, Univ. of...Dec. 13, '12	A. Kalin	H. S. McLaughlin, West Virginia University, Morgantown, W. Va.
West Virginia Univ.....Nov. 13, '14	C. R. Huffman	J. A. Blair, Worcester Polytechnic Institute Worcester, Mass.
Worcester Poly. Inst....Mar. 25, '04	C. W. Kennedy	J. P. Allen, Sheffield Scientific School, New Haven, Conn.
Yale University.....Oct. 13, '11	A. W. Cahoon	

Total 56.

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American Institute of Electrical Engineers

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PROCEEDINGS

Vol. XXXV OCTOBER, 1916 Number 10

INSTITUTE MEETING IN PHILADELPHIA, OCTOBER 13, 1916

The 325th meeting of the American Institute of Electrical Engineers will be held in Philadelphia, October 13, 1916. Since the previous announcement of this meeting it has been decided to change the place of meeting, which will be at the Bellevue-Stratford Hotel at Broad and Walnut Streets. The registration bureau and Institute headquarters will be in the Clover Room of this hotel. The meeting will be under the auspices of the Philadelphia Section and the Power Stations Committee of the A. I. E. E. There will be an afternoon session at 2 o'clock, an informal dinner at 6 o'clock, and an evening session at 8 o'clock. The program in detail is as follows:

Afternoon Session

At Clover Rooms of Bellevue-Stratford Hotel.

1:00 P. M.
Registration office opens.

2:00 P. M.
Technical Session

1. *The Power Company's Problem in the Electric Supply for Large Single-Phase Load*, by Wm. C. L. Eglin.
2. *Supply of Single-Phase Loads from Central Stations*, by Philip Torchio.

6:00 P.M.

Informal dinner, Stratford Room, Bellevue-Stratford Hotel, $1.50 per cover.

8:00 P. M.

3. *Single-Phase Power Production*, by E. F. W. Alexanderson and G. H. Hill.
4. *Single-Phase Power Service from Central Stations*, by R. E. Gilman and C. L. Fortescue.

There will be no October meeting in New York city, and the regular monthly meeting of the Board of Directors will be held in Philadelphia, Friday, October 13, at 10:30 a. m.

INSTITUTE MEETING IN NEW YORK, NOVEMBER 10, 1916

The 326th meeting of the American Institute of Electrical Engineers will be held in the Engineering Societies Building, New York, Friday, November 10, 1916, at 8:15 p. m. The general subject of the meeting will be "Inventories and Appraisals" and the technical program will consist of four papers covering different phases of these subjects which will be provided by the Committee on Economics of Electric Service.

INSTITUTE MEETING IN BOSTON, DECEMBER 8, 1916

The 327th meeting of the American Institute of Electrical Engineers will be held in Boston, Mass., December 8, 1916. The program for this meeting has not been finally determined, but will be announced in an early issue of the PROCEEDINGS. There will be no New York meeting of the Institute in December.

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COMING SECTION MEETINGS

Pittsburgh.—October 21st, 8:00 p.m., Fort Pitt Hotel. Joint meeting with Association of Iron and Steel Electrical Engineers. Abstract of the Central Station Power Committee's Report, presented at Chicago Convention of A. I. & S. E. E. Papers; "Steel Conductors for Transmission Lines" by H. B. Dwight; "The Advantages of Modern Types of Direct-Current Machines" by David Hall. Meeting will be preceded by a dinner to be served at 6:30 p.m.

Toronto.—October 20th, 1916. Address by Mr. Charles B. Scott on "Accident Prevention".

JOINT MEETING WITH A. I. & S. E. E.

The joint session of the A. I. E. E. and A. I. and S. E. E. was held on Wednesday, September 20, during the 10th Annual Convention of the latter society. Two papers on behalf of this Institute were presented as follows:

Underground Distribution Systems, by George W. Newton.

Steel Conductors for Transmission Lines, by H. B. Dwight.

Mr. Newton's paper, which was published in the August issue of the PROCEEDINGS, was read by Mr. H. B. Gear of Chicago, and called forth a discussion of construction details that have been found advantageous in existing underground systems.

Mr. Dwight's paper, which was also published in the August PROCEEDINGS, contained some foreign test data on steel conductors for transmission lines, and the discussion pointed to a demand for test data on American Steel wires showing what sizes and grades of steel are best adapted to this work.

PACIFIC COAST CONVENTION

The Pacific Coast Convention held in Seattle, Wash., September 5-9, 1916, proved a pleasant and profitable meeting for all who attended. The total registration numbered 182 including 29 ladies.

The convention opened Tuesday morning with an address of welcome by Mayor Hiram C. Gill, to which Prof. Harris J. Ryan responded. The technical paper by Messrs. Hoge and Perry entitled *Distribution System for Domestic Power Service from Commercial and Engineering Standpoints* was read and discussed at the morning session. At the afternoon session the paper on *Some Features of Domestic Electric Cooking and Heating* by H. B. Pierce, was read by Mr. G. F. Henderson, and the paper on *Temperature Rise of Insulated Lead Covered Cables* by Richard C. Powell, was read by Mr. E. A. Loew.

The Wednesday morning session was opened by an address by President H. W. Buck, which was followed by the reading and discussion of the paper by Messrs. Griswold and Mastick on *Inductive Interference as a Practical Problem.*

The Wednesday afternoon session was devoted to the reading and discussion of three papers, namely, *Testing for Defective Insulators on High-Tension Transmission Lines* by B. G. Flaherty, *The High-Voltage Potentiometer* by Harris J. Ryan, and *An Artificial Transmission Line with Adjustable Line Constants* by C. E. Magnusson and S. B. Burbank.

On Thursday afternoon, the visiting ladies enjoyed an automobile ride on the boulevards, concluding with a tea at the Boulevard Inn. Thursday evening there was an address by Dr. Henry Suzzallo, President of the University of Washington, at the Metropolitan Theatre, followed by a lecture by Mr. W. D'A. Ryan, on the Lighting of the Panama-Pacific Exposition.

Friday morning the technical session was devoted to reading and discussion of two papers, namely, *Characteristics of Admittance Type of Wave Form Standard* by Frederick Bedell, and *Insulator Failures Under Transient Voltages* by W. D. Peaslee.

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On Friday evening a banquet was held and theatre party for ladies was given at the Orpheum Theatre. Saturday morning was devoted to a trip around Lake Washington on the steamer *Fortuna*, with a stop at Fortuna Park where lunch was served and various field sports enjoyed.

PAST SECTION MEETINGS

Milwaukee.—September 13, 1916. Federal Rubber Company, Cudahy, Wis. Address on "The Growing and Gathering of Rubber Latex" by L. J. D. Healey. Inspection of plant of the Federal Rubber Company. Attendance 130.

Pittsburgh.—September 12, 1916, Fort Pitt Hotel. Subject: Public Utilities Regulation by Commission. Messrs. H. N. Muller, C. I. McCahill, and W. M. Holtz, presented the different phases of Public Utilities Regulation. Attendance 65.

Toledo.—September 12, 1916, Toledo Commerce Club. Lecture by Mr. R. D. Musselman on "The Oscillograph", followed by a demonstration of the working of an oscillograph. Attendance 50.

Toronto.—September 22, 1916, Engineers' Club. Paper: "Electrical Machinery Specifications Based on Modern Standards" by H. M. Hobart. Attendance 75.

ENGINEERS COMBINE WITH SCIENTISTS IN ORGANIZATION OF NATIONAL RESEARCH COUNCIL

Arrangements have just been completed in New York whereby the resources of The Engineering Foundation under the auspices of the four principal American National Engineering Societies are placed at the disposal of the National Research Council, which was appointed by the National Academy of Science at the request of President Wilson. The object of the Council is to coordinate the scientific research work of the country in order to secure efficiency in the solution of the problems of war and peace. The Council was without funds until The Engineering Foundation, established to further scientific and engineering research, offered to place its resources at the Council's disposal, including the services of its secretary, Dr. Cary T. Hutchinson, to act as secretary of the Council. The offer was gladly accepted and plans for immediate activities are in the hands of an executive committee which has been meeting in New York last week.

In indicating how thoroughly every branch of science and engineering is represented in the Council, Dr. George E. Hale, director of the Mt. Wilson Solar Observatory, and chairman of the Council, who was in New York last week attending to the details of the arrangement, called attention to the personnel of the body, saying it is the purpose of the Council to enlist the cooperation in the solution of our industrial and military problems of a scientific character of every possible established agency. Medicine, for example, is represented on the Council by Dr. William H. Welch, President of the National Academy; by Brigadier General William C. Gorgas, Surgeon General of the United States Army, Dr. Simon Flexner, director of the Rockefeller Medical Institute, and Dr. Victor C. Vaughan, past president of the American Medical Society; biological science by Dr. Edwin G. Conklin, professor of zoology, Princeton University; chemistry by Dr. A. A. Noyes of Massachusetts Institute of Technology and Dr. L. H. Baekeland; physics by Dr. A. A. Michelson of the University of Chicago; and electricity by Professor M. I. Pupin, of Columbia University. These branches, with the exception of medicine, are in the realm of pure science. Recognizing, however, that the practical applications of the principles which the pure scientists discover rest largely with engineers there is a strong representation from the great engineering societies. Clemens Herschel, president of the American

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Society of Civil Engineers; John J. Carty, chief engineer of the American Telephone & Telegraph Company, Gano Dunn, president of the J. G. White Engineering Corporation, C. E. Skinner, director of the research laboratory of the Westinghouse Company and Dr. W. R. Whitney, director of the research laboratory of the General Electric Company are among those who will represent the engineering side of the Council's work.

The important military aspects will be presented to the Council by Major General William Crozier, chief of ordnance of the U. S. Army, by Lieutenant Colonel George O. Squier, chief of aviation of the U. S. Army, and Chief Constructor David W. Taylor, U. S. Navy will represent other phases of the military problem. Other branches of the government are represented by Dr. S. W. Stratton, director of the National Bureau of Standards; Van H. Manning, director of the Bureau of Mines; Prof. Chas. F. Marvin, chief of the United States Weather Bureau.

It will thus be seen that the Council includes representatives of all of the important scientific activities bearing on military or industrial problems. The executive committee's plans are of wide scope, the support already pledged will insure immediate action where the need is greatest.

Our English brethren by a similar organization have been of immense assistance to their government during the war. The American organization now being perfected should be of equal value to its government, but it is hoped that the benefits industrially will be no less important than the military ones.

The other members of the Council are Dr. John A. Brashear, of Pittsburgh; Dr. W. F. M. Goss, dean of engineering, University of Illinios; Dr. William H. Holmes, curator United States National Museum; Dr. W. W. Keen, president American Philosophical Society; Prof. E. C. Pickering, director of the Harvard College Observatory; Mr. Charles F. Rand, president United Engineering Society; Prof. Theodore W. Richards, Harvard University; Professor Millikan of the University of Chicago; Mr. Ambrose Swasey, of Cleveland; Dr. Elihu Thomson, Swampscott, Mass. Dr. C. R. Van Hise, president of the American Association for the Advancement of Science; Dr. Charles D. Walcott, secretary of the Smithsonian Institution; Dr. J. M. Coulter, Professor of botany at Princeton University.

WORK OF THE COMMITTEE ON INDUSTRIAL PREPAREDNESS

The following letter recently written by Thomas A. Edison, Chairman of the Naval Consulting Board, gives a comprehensive statement of the work accomplished by the Industrial Preparedness Committee which, as announced in the March 1916 PROCEEDINGS, was appointed at the invitation of the President of the United States to assist the Naval Consulting Board in collecting data for use in organizing the manufacturing resources of the country for the public service in case of emergency. The names of A. I. E. E. representatives on this committee were published in the May, 1916 PROCEEDINGS.

The Committee on Industrial Preparedness of the Naval Consulting Board, of which committee Howard E. Coffin is chairman, after a five months campaign in many ways unique in vigor and vision, has played a very definite part in the measures for the national defense which have just become law. It is responsible for having laid the foundation for a true industrial preparedness in this nation.

Five months ago the committee, wholly non-partisan in make-up, acting with the civil, mechanical, mining and electrical engineers and the chemists of the country, members of five great scientific bodies, began its work in every nook and cranny of the land. The purpose was to prepare American industry efficiently to support the armed forces of America in the event of war.

The public, the business men and the legislators at Washington knew little regarding the demands on industry in connection with modern war. No department at Washington was charged

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with the duty of coordinating the needs of the army and navy with transportation, industry, and kindred functions. The purchasing, quartermaster's and ordnance departments of the army and navy were unable to buy military supplies except by competitive offering in open market. No one had considered the need, and no legislative machinery was in existence, for preventing the presence of skilled workers on the fighting front when they would in time of war be needed in the factories, mills and mines of the country. Neither at Washington or elsewhere was there even a list of the industrial resources of the nation in such shape as could be used for practical purposes in case war should come.

The three things, then, that the committee headed by Mr. Coffin set out to do and that now have been brought about were as follows: First, to mobilize concretely the business men of America and their output against a day of need. This meant chiefly to discover in fullest detail just what equipment our manufacturers possessed that might be swung over to supply the army and navy swiftly and bountifully from the hour the colors were raised. In a few weeks this initial task, which has been a truly colossal one, will be at an end. A complete report of the equipment of practically every concern of substantial size in the country is now in the hands of the committee. Directly in charge of the great inventory has been W. S. Gifford, Supervising Director of the Committee.

The second step was to procure legislation making possible the placing by the war and navy departments of annual orders for munitions in small quantities to American manufacturers now not producing such things, so that quietly, efficiently and thoroughly they could learn in time of peace how to supply the government in time of war. The new laws make all this possible. It should be said here that this practise will bring about a geographical diffusion of munition plants all over our country, instead of affording us only a few such concerns for the most part near the exposed seaboards, as at present. It is obvious that this system will also throttle all talk of a munitions trust.

Further to teach manufacturers how to produce munitions, the army appropriation bill permits the purchase of "gages, dies, jigs, tools, fixtures, and other special aids and appliances, including specifications and detailed drawings necessary for the manufacture by the government and by private manufacturers of ammunition necessary for the use of the land forces of the United States in time of war." This has been one of the crying needs that the committee has emphasized.

The third step was to cause skilled labor in America to be enrolled in an industrial reserve. For, as Mr. Coffin has repeatedly told the country, it takes but ten or twelve months to turn out a soldier, but years to make a toolmaker. All this is provided for in the army reorganization bill just signed.

At the same time there has been created the council of National Defense, composed of the secretaries of war, navy, interior, agriculture, commerce, and labor, and seven civilians, each eminent in his respective field and each to serve the government of the United States without pay, as we on the Naval Consulting Board have been doing.

Part of the new act reads—and every American citizen should know about it—

> That it shall be the duty of the Council of National Defense to supervise and direct investigations and make recommendations to the President and the heads of executive departments as to the location of railroads with reference to the frontier of the United States so as to render possible expeditious concentration of troops and supplies to points of defense; the coordination of military, industrial and commercial purposes in the location of extensive highways and branch lines of railroads; the utilization of waterways; the mobilization of military and naval resources for defense; the increase of domestic production of articles and materials essential to the support of armies and of the people during the interruption of foreign commerce; the development of seagoing transportation; data as to amounts, location, method and means of production, and availability of military supplies; the giving of information to producers and manufacturers as to the class of supplies needed by the military and other services of the Government, the requirements relating thereto, and the creation of relations which will render possible in time of need the immediate concentration and utilization of the resources of the Nation.

The work of the Committee on Industrial Preparedness will almost surely be turned over to the new Council, the committee's remarkable constructive programme being in effect already an accomplished fact. With this accomplishment comes not merely a better understanding between the business men of America and their government but it marks almost dramatically the entrance of the trained, non-partisan engineer, doing his job on the sole basis of efficiency, integrity and Americanism, into the affairs of government.

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But the greatest service which the committee has rendered to our people and government has been to drive home the vital, irresistible truth that in war as now waged battles are won not alone by fighting men but by the fighting industries of a nation.

NATIONAL ENGINEER RESERVE

On July 1st the new law providing for the National Reserve Corps of Engineers became effective. A general outline of this legislation was published in the March 1916 PROCEEDINGS as reported by the Joint Committee of five national engineering societies which had been appointed to assist the War Department in the formation of the National Engineer Reserve. The War Department has recently completed details of requirements and qualifications for commissions in the officers reserve corps of the army, which are embodied in a circular issued by the Joint Committee of the engineering societies and which has been mailed to every member of the A. I. E. E., and the other participating societies.

Commissions will be issued for the rank of Major, Captain, First and Second Lieutenant. The commissions will be for five years renewable however with the approval of the Secretary of War and after a physical examination. Holders of commissions are subject in time of peace to duty in instruction camps and elsewhere of two weeks each year, or longer with the officers consent, and it is expected that a reasonable latitude in the choice of time for this service will be allowed. They are subject to order to duty by the President whenever war is actual or imminent in a rank not below that held in the Reserve Corps of Engineers. Enlisted men of the regular army and of the national guard, both active and retired, if citizens of the United States, are eligible for examination for commissions in the Officers Reserve Corps. No applicant will be examined who is an officer of the regular army, on the active list of the National Guard, or who is not a citizen of the United States.

No mental examination will be undertaken of an applicant who is in the judgment of the examining board not physically qualified.

Every applicant is subject to a rigid physical examination and if any cause of disqualification is found which might in future impair his efficiency as an officer, he will be rejected. Defects of vision which may be entirely corrected by glasses do not disqualify unless they are due to or accompanied by organic disease.

Candidates for appointment in the Engineers Officers' Reserve Corps will be examined either (*a*) for duty with combatant engineer troops or other duties in the service of the front, or (*b*) for special service on the lines of communications or other points in rear, including engineer work in connection with seacoast defenses, as hereinafter indicated. Officers appointed under (*b*) will not ordinarily be assigned to combatant duties, but will be subject to such assignment whenever needed. The examinations shall be especially directed to ascertaining the practical capacity of the applicant, and the record of previous service and training of the applicant shall be considered as a part of the examination.

Military experience or training in the Regular Army, Volunteers, or National Guard, or at training camps or educational institutions will be noted and reported by the board and considered in making the recommendations.

A. QUALIFICATIONS FOR RESERVE OFFICERS, SERVICE OF THE FRONT

1. For First and Second Lieutenants.

(*a*) The applicant must be an engineer in the active practise of his profession or some business immediately connected with, or concerned in, engineering matters.

(*b*) He must either hold or have qualified for the grade of Junior Engineer, civil, electrical, or mechanical or higher

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grade in the civil service, or he must be a graduate from an approved engineering college, or have been in the above practise of engineering for at least two years.

2. For Captains.

(*a*) As above.

(*b*) He must either hold or be eligible for the grade of Assistant Engineer in the Engineer Department at large, or a corresponding Engineer grade in the civil service in another department of the Government service, or have held a commission in the Corps of Engineers of the Regular Army, or shall be a professional engineer not less than 28 years of age, who shall have been in the active practise of his profession for at least 8 years and have had responsible charge of work as principal or assistant for at least 2 years. Graduation from a school of engineering of recognized reputation shall be considered as equivalent to two years' active practise.

(*c*) Knowledge of the principles of military organization and operations, as illustrated in Infantry Drill Regulations, Parts I (to include School of the Company) and II, and Field Service Regulations, Part I and Part II (Articles I, II, IV, VI); and of the general principles of field fortifications, as illustrated in the Engineer Field Manual, Chapter V.

3. For Majors.

(*a*) As above.

(*b*) He must hold the grade of Assistant Engineer in the Engineering Department at large, or corresponding Engineer grade in the civil service in another department, or have held a commission in the Corps of Engineers of the Regular Army not more than two grades below that for which he desires to be listed, or shall be a professional engineer not less than 35 years of age, and shall have been in the active practise of his professiod for 15 years, who shall have had responsible charge of work for at least 5 years, and who shall be qualified to design as well as to direct engineering work. Graduation from a school of engineering of recognized reputation shall be considered as equivalent to two years of active practise.

(*c*) In addition to fulfilling the qualifications given in Paragraph 3 (*a*) and (*b*), the candidate will be required to pass an examination on the following subjects:

Drill regulations, field service regulations, duties of engineer officers and troops in war, and co-operation between the various arms of the service.

All examinations will be oral.

B. QUALIFICATIONS FOR RESERVE OFFICERS, SPECIAL SERVICES:

Candidates desiring appointment in special services must be qualified for at least one of the duties assigned to the Corps of Engineers by the following extracts from Army Regulations:

"1493. The duties of the Corps of Engineers comprise reconnoitering and surveying for military purposes, including the laying out of camps; selection of sites and formation of plans and estimates for military defenses; construction and repair of fortifications and their accessories; . . . the installation of electric power plants and electric power cable connected with seacoast batteries; . . . construction and repair of military roads, railroads, and bridges; military demolitions; . . . In time of war within the theatre of operations it has charge of the location, design, and construction of wharves, piers, landings, storehouses, hospitals, and other structures of general interest, and of the construction, maintenance and repair of roads, ferries, bridges and incidental structures, and of the construction, maintenance, and operation of railroads under military control, including the construction and operation of armored trains."

No oral or professional examinations will be required, but recommendations of boards will be required in lieu of such examinations. Candidates will submit evidence of their actual employment in corresponding or higher positions in

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civil life and references to persons under whom they have been or are employed.

The Board will communicate with such persons and with any others that they deem fit and upon all the evidence submitted and otherwise obtained, will base their recommendations and recommend the appropriate grades for which they deem the successful candidates qualified.

Reserve officers from the following civilian occupations will be required for the special services of the Corps of Engineers:

Bridge engineers,

Construction engineers (earth and concrete),

Constructing engineers (wharves, piers, and buildings),

Electrical engineers (for small plants and power lines),

Highway engineers,

Mining engineers (skilled in tunneling and use of explosives),

Railroad engineers (construction and maintenance),*

Railroad operating officials,*

Sanitary engineers,

Topographical engineers.

There is no maximum age limit for the Engineer Officers' Reserve Corps.

Engineers desiring to avail themselves of the opportunity thus presented for honorable service in the army of the United States should at once send to the Chief of Engineers, War Department, Washington, D. C., for application blanks to be filled out and returned to him.

A list of typical examination questions is appended to the above mentioned circular.

PERSONAL

MR. CLIFFORD W. BATES, who has been instructor in electrical engineering in the Sheffield Scientific School of Yale University, has resigned in order to accept a position in the instrument and installation department of the Philadelphia Electric Company.

MR. ROBERT P. WINTON has resigned his position as instructor in electrical engineering in the Sheffield Scientific School of Yale University to accept a position in the construction department of the Philadelphia Electric Company.

MESSRS. F. B. H. PAINE, WILLIAM MCCLELLAN and HORACE T. CAMPION announce that they have formed a partnership. The firm is known as Paine, McClellan and Campion, engineers, with offices at 25 Church Street, New York, and 1420 Chestnut Street, Philadelphia.

MR. ROBERT HOLMES has resigned his position as electrical engineer of the Wayagamuck Pulp and Paper Company, Limited, Three Rivers, Quebec, to resume his former position on the staff of T. Pringle and Son, Limited, consulting engineers, Montreal.

MR. RUSSELL G. WARNER, who has been for the last two years in the engineering department of the Westinghouse Electric and Manufacturing Company, has been appointed assistant in electrical engineering in the Sheffield Scientific School of Yale University, of which he is a graduate. Mr. Warner was chairman of the Yale Branch, A. I. E. E., in 1913-14.

MR. J. E. FRIES, who has been connected with the Crocker-Wheeler Company since February, 1908, in the various capacities of industrial engineer, Pacific Coast engineer, and assistant chief engineer, has resigned the last-named position to become chief electrical engineer of the Tennessee Coal, Iron and Railroad Company, Birmingham, Alabama.

MR. HAROLD V. BOZELL has been appointed assistant professor in the

* Railroad officials desiring to serve in connection with the transportation of troops and supplies on commercial lines in the zone of the interior, namely, outside of the theatre of operations (see Quartermaster's Corps).

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electrical engineering department of the Sheffield Scientific School of Yale University for the coming college year, for which period he has secured leave of absence from the University of Oklahoma, where he was director of the School of Electrical Engineering and professor of electrical engineering. Professor Bozell is a graduate of the University of Kansas.

MR. GILBERT ROWE, of London, England, has been in this country for the past 14 months purchasing engineering materials for British firms under the Munitions Act. He is returning to England before the end of the year, and would be glad to hear from anyone desiring any technical information from the other side, or reports as to the conditions for American electrical manufacturers. Mr. Rowe's present address is the Engineers' Club, 32 W. 40th Street, New York City.

MR. EDWARD J. CHENEY has been promoted to be chief of the Division of Light, Heat and Power in the New York State Second District Public Service Commission. He has been assistant chief of the division for the last four years, and prior to that was on the engineering staff of the General Electric Company at Schenectady. He succeeds Mr. Edward McGuire, who has resigned from the service and returned to Buffalo to engage in private business. Mr. Cheney has moved from Schenectady to Albany, making his home at 874 Lancaster Street.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before October 31, 1916.

Benninger, M. P., Balboa, C. Z.
Bolton, I. W. (Member), Milwaukee, Wis.
Bullard, W. R., New York, N. Y.
Cowin, S. H., East Pittsburgh, Pa.
D'Alton, F. K., Toronto, Ont.
Del Puglia, A., Milan, Italy
d'Oliveira, E., Bahia, Brazil
Dudley, N. L. Mt. Hope, N. J.
Dunn, S. E., Berkeley, Cal.
Egan, L. W., Midland, Pa.
Farquhar, J. F., Spokane, Wash.
Fedotoff, N.V. (Member) Paterson, N. J.
Gastmeyer, R. W., New York, N. Y.
Hague, A. E., New York, N. Y.
Harvey, C. H. (Member), Knoxvlile, Tenn.
Hawkins, P. D. (Member), Boston, Mass.
Hough, R. H. Philadelphia, Pa.
Janson, G. W., New York, N. Y.
Kettlewell, J. E., Iditarod, Alaska
Leitner, F. L., Brooklyn, N. Y.
Lentz, R. V., Leeton, Mo.
Lionberger, H. L., Spokane, Wash.
Lipscomb, W. H., New York, N. Y.
Macy, H. D., Oak Ridge, Va.
McConnell, J. J., Rayville, La.
Moore, C. J., Stillwater, Okla.
Press, A., Norman, Okla.
Preston, C. R., Dallas, Tex.
Robertson, A. J., Visalia, Cal.
Salisbury, A.J. (Member), Toronto, Ont.
Schindler, R. A., Milwaukee, Wis.
Seeger, E. W., Milwaukee, Wis.
Shaver, J. H., Elizabethport, N. J.
Shevalin, V. A., Eddystone, Pa.
Slutter, W., Vintondale, Pa.
Smith, E. G., Central Aguirre, P.R.
Staples, W. D., Kansas City, Mo.
Stevens, E. M., Kansas City, Mo.
Stockberger, M. H., New York, N. Y.
Stone, R. R., Wheeling, W. Va.
Thoms, A. P., Chicago, Ill.
Tomann, O. R., Red Oak, Ia.
van Aernam, J. H., Pittsburgh, Pa.
van Nieukerken, J. M., E. Pittsburgh, Pa.
Wagner, G. E., Madison, Wis.
Weber, R. L., Kansas City, Mo.
Wood, L. F., Norman, Okla.
Total 47.

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EMPLOYMENT DEPARTMENT

Note: Under this heading brief announcements (not more than fifty words in length) of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months: during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

VACANCIES

V-153. Engineering Graduate, designer of small intricate machinery. Permanent position.

V-169. A New England concern is desirous of securing several progressive young men who have a general knowledge of electric motors and their application, also good sales records. Kindly give all particulars.

V-170. Opportunity for young technical graduate, three or four years out of college, who has had some experience in purchasing, estimating or contracting; also some business experience. Practical experience in connection with steam engine, gas or hydraulic work desirable, but not absolutely essential. Give full particulars.

V-171. Chemical Engineer with experience in organizing plant for position as departmental engineer in dye works. Please give full details of experience and salary expected.

V-173. Wanted for engineering school in Middle West, electrical engineer with drafting experience to take charge of electro-mechanical drawings, and to lecture on electrical subjects. Salary $1500 to $1800, depending upon experience.

V-174. Wanted by Engineering school in Middle West, electrical engineer as assistant professor of electrical machine design. State experience salary expected, age and other details.

V-175. Opening for recent technical graduate as assistant in laboratory in telegraph signaling work. Good opportunity for advancement; moderate salary to start. Must be resident of New York City or vicinity.

V-176. Draftsman, with experience in power station layout. Give details of experience and salary desired.

MEN AVAILABLE

564. Electrician, age 26, married, Eight years' experience in construction and maintenance. All-round experience, including heavy power and electric furnace installations. At present chief electrician; semi-technical education.

565. Maine Yankee, age 30, married, temperate, energetic, desires position as manager of light, heat and power company in town of 5,000 to 10,000. Has increased present business 300 per cent, besides handling all electrical work in textile mill using 1400 h. p. of three-phase motors.

566. Electrical Engineer. Two and a half years' experience in operation; six years' experience in design of all kinds of electrical installations, including generators, motors, rotary converters, batteries, transformers, railway equipment. Desires position of responsibility with operating company or consulting engineer. Now employed.

567. Electrical Engineer, technical graduate, now open for engagement. Two years' experience in the design of lighting and power systems for all classes of buildings; one year's experience in underground and overhead electrical construction. Age 26.

568. Graduate Electrical Engineer, age 30, married, good character. Desires position with consulting engineer or in electrical research engineering. Has had General Electric test and six years' experience in industrial control engineering work.

569. Electrical Engineer, age 33, desires to make connection with manufacturing, engineering or contracting concern. Eleven years' experience with consulting electrical engineers in New York City.

570. Ignition Expert, with large experience in all branches of electricity pertaining to the automobile. For past eight years chief electrical engineer and scientific advisor of one of the largest magneto and coil manufacturers in America. Former patentee of numerous

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ignition apparatus and systems, and still capable of furnishing others of much merit.

571. Graduate New York Electrical School, age 24, desires position, preferably with consulting or construction engineers and contractors, but will consider anything where ability will lead to advancement. Has had several years' experience as wireman and in general repair work. Salary secondary to permanence and future prospects of the position.

572. Testing Engineer for large hydro-electric system on Pacific Coast, desires a similar position, or one as superintendent of small plant, or one as assistant electrical engineer. Will locate anywhere. Excellent reasons for desiring change. Technical, practical, and seven years in G. E. testing department; specialized on meters. Four years in present position.

573. International Correspondence School graduate, student in New York Electrical day school; three years' electrical experience, wishes employment with consulting electrical engineer where he has good chance to learn business. Will go anywhere in the East. Age 21.

574. Electrical Engineer, age 28, single, good character. General Electric test and standardizing laboratory experience. Many years with large gas and electric company. Exceptional commercial, engineering and executive training. Good mechanic and workman. Desires position with operating or construction company. Will go anywhere, but Pacific Coast preferred.

575. Mem. A. I. E. E. and A. S. M. E., college and technical graduate, desires position, subordinate or otherwise, in or near New York preferred. Has broad experience of eighteen years in design, construction and operation of power plants, substations, motor applications and high-tension transmission. Has proved executive ability, a good correspondent, adaptable, systematic, and reliable.

576. Engineer, two years' shop experience, four years' college training in electrical and mechanical engineering, good linguist, eighteen years' design, estimates, specifications, construction, testing and operation of electric generating, distribution, light and power plants of every description; successful organizer, managing sales and office force, handling labor, desires permanent position with future prospects.

577. Electrical and Mechanical Engineer, now employed, desires change. Experienced in design and supervision of power plant construction and operation, electrical distributing systems, both overhead and underground construction and maintenance. Mechanical and electrical repair shop practise. Supervision and management of boiler rooms and mechanical refrigerating apparatus, steam turbines and engines.

578. Electrical and Chemical Engineer, technical graduate, with eight years' experience in research and supervision of factory development, wishes position with consulting engineer or manufacturer, where application of advanced chemistry and electrochemistry to factory processes is desired. Research and development of inventions a specialty. At present employed.

579. Technical graduate—seven years' experience—electric railway and power station, design, testing and operating. One year apprentice with G. E. Co. At present employed, but desires position with greater opportunity for advancement.

580. Appraisal Engineer, age 30, Mass. Inst. of Tech. graduate. Five years' experience; two years in electric light, power, and telephone appraisal.

581. Telephone Engineer, age 38, university graduate, now employed. Fifteen years' experience with Bell and independent operating and manufacturing companies on central office, substation and outside equipment, covering maintenance, construction, reconstruction, methods, specifications, appraisals and instructions.

582. Lighting and power systems. Experienced construction man (B.E.E.) who has designed and supervised the installation of a large number of industrial and residential systems, desires connection with contractors or engineers where initiative is permitted. Capable estimator and draftsman.

583. Electrical Engineer, age 32, ten years' experience as construction foreman, engineer and manager of various properties, wishes new position as engineer, superintendent or manager. Now employed as superintendent of power for progressive utility company in New York State. Location immaterial. Personal interview desired.

584. Foreman of electrical construction; fourteen years' experience—office buildings, factories, plants, theaters, hotels. Three years' technical training estimating experience; available now.

585. Electrical Engineer, technical graduate, fifteen years' practical experience. Nine years with General

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Electric Co., including testing, construction work, design and laboratory. Also operating experience. Prefer Southwest. Age 37; married.

ACCESSIONS TO LIBRARY

This list includes books on electrical subjects only, which have been added to the library of the A. I. E. E. and the U. E. S. during the past month, not including periodicals and other exchanges.

Costruzioni Elettromeccaniche. pt. 6. By Ettore Morelli. Torino, 1916. (Gift of Unione Tip. Editrice Torinese.)

Hadfield's Low Hysteresis Steel. Pamphlets (Gift of Sir Robert A. Hadfield.)

Underwriters Laboratories. Electrical Data August 1916.

——Tentative Standard for the construction and installation of materials for lightning rod equipments. May 1916. (Gift of Underwriters' Laboratories.)

Utilization of Atmospheric Nitrogen. Washington, 1912. (Gift of U. S. Department of Commerce & Labor.)

UNITED ENGINEERING SOCIETY

Emission of Electricity from Hot Bodies. By O. W. Richardson, London, 1916. (Purchase.)

Pennsylvania. Department of Internal Affairs. Part IV. Railroad Canal, Navigation, Telegraph and Telephone companies, 1915. Harrisburg, 1916. (Purchase.)

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OFFICERS AND BOARD OF DIRECTORS, 1916-1917.

PRESIDENT.

(Term expires July 31, 1917)
H. W. BUCK

JUNIOR PAST-PRESIDENTS.

(Term expires July 31, 1917)
PAUL M. LINCOLN

(Term expires July 31, 1918)
JOHN J. CARTY

VICE-PRESIDENTS.

(Term expires July 31, 1917)
C. A. ADAMS
J. FRANKLIN STEVENS
WILLIAM McCLELLAN

(Term expires July 31, 1918)
B. A. BEHREND
P. JUNKERSFELD
L. T. ROBINSON

MANAGERS.

(Term expires July 31, 1917)	(Term expires July 31, 1918)	(Term expires July 31, 1919)
FREDERICK BEDELL	C. E. SKINNER	CHARLES S. RUFFNER
BANCROFT GHERARDI	F. B. JEWETT	JOHN B. FISKEN
A. S. McALLISTER	JOHN B. TAYLOR	CHARLES ROBBINS
JOHN H. FINNEY	HAROLD PENDER	N. A. CARLE

TREASURER (Term expires July 31, 1917) **SECRETARY.**

GEORGE A. HAMILTON — F. L. HUTCHINSON

HONORARY SECRETARY.
RALPH W. POPE

LIBRARIAN.
W. P. CUTTER

GENERAL COUNSEL.
PARKER and AARON,
52 Broadway, New York.

PAST PRESIDENTS.—1884-1916.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMPSON, 1889-90
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-92
FRANK JULIAN SPRAGUE, 1892-3.
*EDWIN J. HOUSTON, 1893-4-5.
*LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-02
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4
JOHN W. LIEB, 1904-5
SCHUYLER SKAATS WHEELER, 1905-6
SAMUEL SHELDON, 1906-7.
HENRY G. STOTT, 1907-8
LOUIS A. FERGUSON, 1908-09.
LEWIS B. STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.
RALPH D. MERSHON, 1912-13.
C. O. MAILLOUX, 1913-14.
PAUL M. LINCOLN, 1914-15.
JOHN J. CARTY, 1915-16.

*Deceased.

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INSTITUTE COMMITTEES.

Revised to October 1, 1916.

GENERAL STANDING COMMITTEES.

EXECUTIVE COMMITTEE.

H. W. Buck, Chairman,
49 Wall Street, New York.

N. A. Carle,	George A. Hamilton,
John H. Finney,	William McClellan,
Bancroft Gherardi,	J. Franklin Stevens.

FINANCE COMMITTEE.

J. Franklin Stevens, Chairman,
1326 Chestnut Street, Philadelphia, Pa.

N. A. Carle,	Bancroft Gherardi.

MEETINGS AND PAPERS COMMITTEE.

L. T. Robinson, Chairman,
General Electric Company, Schenectady, N.Y.
L. W. Chubb, Secretary, W. E. and M. Co. East Pittsburgh, Pa.

Frederick Bedell,	P. W Peek, Jr.
Philander Betts,	F. L. Rhodes,
J. G. De Remer,	D. W. Roper,
H. A. Hornor,	Harris J. Ryan,
Edward P. Hyde,	T. H. Schoepf
L. E. Imlay,	Charles P. Steinmetz,
E. H. Martindale,	N. W. Storer,

Wilfred Sykes.

EDITING COMMITTEE.

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Columbia University, New York.

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M. G. Lloyd,	C. E. Skinner.

CODE COMMITTEE.

Farley Osgood, Chairman,
763 Broad Street, Newark, N. J.

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H. B. Gear,	G. A. Sawin,
A. H. Griswold,	A. M. Schoen,
H. O. Lacount,	George F. Sever,
Johnston Livingston,	C. E. Skinner,
Henry N. Muller	H. S. Warren.

BOARD OF EXAMINERS.

A. S. McAllister, Chairman,
Engineers' Club, 32 West 40th Street, New York.

E. B. Katte,	W. I. Slichter,
F. L. Rhodes,	Philip Torchio.

SECTIONS COMMITTEE.

W. A. Hall, Chairman,
General Electric Company, West Lynn, Mass.

J. G. De Remer,	A. M. Schoen,
Paul M. Lincoln,	J. H. Tracy,

and the chairmen of all Institute Sections, *ex-officio.*

MEMBERSHIP COMMITTEE.

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1000 Chestnut Street, Philadelphia, Pa.

G. M. Baker	W. G. Chace,
S. H. Blake,	H. W. Flashman,

E. H. Martindale.

and the chairmen of the Membership Committees of all Sections.

PUBLIC POLICY COMMITTEE.

Calvert Townley, Chairman,
165 Broadway, New York.

E. A. Carolan,	William McClellan,
John J. Carty,	H. H. Porter,
Fredk. Darlington,	C. S. Ruffner,
Gano Dunn,	A. M. Schoen,
John B. Fisken,	L. B. Stillwell,
A. M. Hunt,	H. G. Stott.

COMMITTEE ON DEVELOPMENT OF WATER POWER.

John H. Finney, Chairman,
509 Metropolitan Bank Building, Washington, D. C.

F. O. Blackwell,	E. A. Lof,
Francis Blossom,	W. V. N. Powelson,
Gano Dunn,	L. B. Stillwell,
Nicholas S. Hill, Jr.,	H. G. Stott.

STANDARDS COMMITTEE.

C. A. Adams, Chairman,
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Harold Pender, Secretary,
University of Pennsylvania, Philadelphia, Pa.

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Frederick Bedell,	A. E. Kennelly,
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James Burke,	A. S. McAllister,
G. A. Burnham,	W. M. McConahey,
N. A. Carle,	W. L. Merrill,
E. J. Cheney,	Charles Robbins,
E. H. Colpitts,	L. T. Robinson,
F. P. Cox,	C. H. Sharp,
W. A. Del Mar,	C. E. Skinner,
E. J. Edwards,	A. J. Slade,
H. W. Fisher,	N. W. Storer,
H. M. Hobart,	H. G. Stott,
H. D. James,	R. B. Williamson.

UNITED STATES NATIONAL COMMITTEE OF THE INTERNATIONAL ELECTROTECHNICAL COMMISSION.

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20 Nassau Street, New York.
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A. E. Kennelly, Secretary,
Harvard University, Cambridge, Mass.

C. A. Adams,	E. B. Rosa,
B. A. Behrend,	Charles F. Scott,
Louis Bell,	Clayton H. Sharp,
James Burke,	Samuel Sheldon,
John J. Carty,	C. E. Skinner,
Gano Dunn,	Charles P. Steinmetz,
H. M. Hobart,	H. G. Stott,
John W. Lieb,	Elihu Thomson,
R. B. Owens,	Philip Torchio.
M. I. Pupin,	

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Ralph D. Mershon, Chairman,
80 Maiden Lane, New York.

Bion J. Arnold,	Charles A. Terry,
John F. Kelly,	B. F. Wood.

EDISON MEDAL COMMITTEE.

Appointed by the President for terms of five years.

Term expires July 31, 1917.

A. E. Kennelly, Chairman, Robert T. Lozier,
S. G. McMeen.

Term expires July 31, 1918.

H. W. Buck, F. A. Scheffler,
J. Franklin Stevens.

Term expires July 31, 1919.

Charles F. Brush N. W. Storer
C. C. Chesney.

Term expires July 31, 1920.

Carl Hering Harris J. Ryan
H. G. Stott.

Term expires July 31, 1921.

W. C. L. Eglin, Bancroft Gherardi,
E. W. Rice, Jr.

Elected by the Board of Directors from its own membership for terms of two years.

Term expires July 31, 1917.

B. A. Behrend, Paul M. Lincoln,
William McClellan.

Term expires July 31, 1918.

C. A. Adams, Harold Pender,
C. E. Skinner.

Ex-Officio.

H. W. Buck, President,
George A. Hamilton, Treasurer,
F. L. Hutchinson, Secretary.

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Revised to October 1, 1916.

POWER STATIONS.

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100 Broadway, New York.

J. M. Drabelle,	R. J. S. Pigott,
C. C. Egbert,	Cecil Poole,
W. S. Gorsuch,	E. F. Scattergood,
John Harisberger,	F. A. Scheffler,
A. H. Kruesi,	H. G. Stott,
Paul M. Lincoln,	W. R. Thompson,
Wynn Meredith,	Philip Torchio,
I. E. Moultrop,	H. L. Wallau,
S. A. Moss,	B. F. Wood.

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Niagara Falls Power Co., Niagara Falls, N. Y.

H. A. Barre,	P. M. Lincoln,
M. T. Crawford,	W. E. Mitchell,
E. E. F. Creighton,	G. J. Newton,
H. H. Dewey,	L. C. Nicholson,
P. M. Downing,	W. D. Peaslee,
H. W. Fisher,	Stefaan Piek,
F. A. Gaby,	C. S. Ruffner,
W. T. Goddard,	H. J. Ryan,
O. A. Havill,	F. D. Sampson,
R. F. Hayward,	H. E. Shedd,
J. P. Jollyman,	Julian C. Smith,

P. H. Thomas.

TRACTION AND TRANSPORTATION.

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Harry H. Adams,	P. J. Kearny,
A. H. Babcock,	William McClellan,
Reinier Beeuwkes,	John Murphy,
E. J. Blair,	W. B. Potter,
L. P. Crecelius,	E. D. Priest,
J. V. B. Duer,	Charles H. Quinn,
George Gibbs,	Clarence Renshaw,
W. J. Harvie,	A. S. Richey,
Hugh Hazelton,	Charles F. Scott,
E. B. Katte,	John B. Taylor,

H. S. Warren.

ELECTRICITY FOR INDUSTRIAL AND DOMESTIC USE.

E. H. Martindale, Chairman,
National Carbon Co., Cleveland, Ohio.

J. H. Davis,	C. A. Kelsey,
A. M. Dudley,	C. L. Kennedy,
Herbert B. Dwight,	Charles D. Knight,
F. W. Ells,	A. H. Lawton,
J. E. Fries,	A. M. MacCutcheon,
F. R. Fishback,	A. G. Pierce,
R. H. Goodwillie,	James M. Smith,
A. L. Hadley,	H. Weichsel,
G. A. Johnstone,	J. B. Wiard,

R. B. Williamson.

LIGHTING AND ILLUMINATION.

Edward P. Hyde, Chairman,
Nela Park, Cleveland, O.

G. M. Chamberlin,	Richard C. Powell,
C. E. Clewell,	E. B. Rosa,
J. R. Cravath,	W. D'A. Ryan,
T. S. Perkins,	Clayton H. Sharp,

W. M. Skiff.

ECONOMICS OF ELECTRIC SERVICE.

Philander Betts, Chairman,
790 Broad Street, Newark, N. J.
(Other members to be announced later)

PROTECTIVE DEVICES.

D. W. Roper, Chairman
Room 500, 72 W. Adams St., Chicago, Ill.

L. L. Elden,	A. A. Meyer,
G. Faccioli,	L. C. Nicholson,
V. E. Goodwin,	N. L. Pollard,
E. M. Hewlett,	S. D. Sprong,
Paul M. Lincoln,	Philip Torchio,

H. R. Woodrow.

ELECTROCHEMISTRY AND ELECTROMETALLURGY.

T. H. Schoepf, Chairman,
W. E. and M. Company, East Pittsburgh, Pa.
(Other members to be announced later)

ELECTROPHYSICS.

F. W. Peek, Jr., Chairman,
General Electric Company, Pittsfield, Mass.

Frederick Bedell,	E. B. Rosa,
A. C. Crehore,	Harris J. Ryan,
G. Faccioli,	Clayton H. Sharp,
C. L. Fortescue,	C. P. Steinmetz,
W. S. Franklin,	P. H. Thomas,
A. E. Kennelly,	J. B. Whitehead.

TELEGRAPHY AND TELEPHONY.

F. L. Rhodes, Chairman,
15 Dey St., New York.

E. F. W. Alexanderson,	Kempster B. Miller,
R. E. Chetwood,	H. Mouradian,
M. M. Davis,	W. O. Pennell,
C. L. Fortescue,	Allard Smith,
H. M. Friendly,	John S. Stone,
F. B. Jewett,	John B. Taylor,
S. M. Kintner,	J. L. Wayne, 3rd,
Wm. Maver, Jr.,	G. M. Yorke.

USE OF ELECTRICITY IN MARINE WORK.

H. A. Hornor, Chairman,
Hamilton Court, 39th & Chestnut Sts., Philadelphia, Pa.
D. M. Mahood, Secretary,
Sperry Gyroscope Company,
Manhattan Bridge Plaza, Brooklyn, N. Y.

R. B. Chillas, Jr.,	Guy Hill,
M. W. Day,	O. P. Loomis,
G. E. Edgar,	G. A. Pierce, Jr.,
W. L. R. Emmet,	H. M. Southgate,
W. R. Furlong,	E. A. Sperry,
H. L. Hibbard,	Wilfred Sykes,

F. W. Wood.

USE OF ELECTRICITY IN MINES.

(Not yet appointed.)

IRON AND STEEL INDUSTRY.

Wilfred Sykes, Chairman,
Box 242, East Liberty, Pa.

S. C. Coey,	A. G. Pierce,
F. B. Crosby,	J. C. Reed,
E. Friedlaender,	R. Tschentscher,
E. S. Jefferies,	Brent Wiley,
D. M. Petty,	J. H. Wilson.

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SPECIAL COMMITTEES.

Revised to October 1, 1916.

REORGANIZATION OF TECHNICAL COMMITTEES.

L. T. Robinson, Chairman,
General Electric Company, Schenectady, N. Y.
F. L. Hutchinson, H. H. Norris,
A. S. McAllister, J. Franklin Stevens,
N. W. Storer.

PROPOSED RESERVE CORPS OF ENGINEERS.

Bion J. Arnold, Chairman,
105 South La Salle Street, Chicago, Ill.
John Harisberger, A. M. Schoen,
Ralph D. Mershon, Charles W. Stone.

INSTITUTE REPRESENTATIVES.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

Ralph D. Mershon, Paul M. Lincoln,
C. O. Mailloux, John J. Carty.

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

H. H. Barnes, Jr., Gano Dunn,
Samuel Sheldon.

ON LIBRARY BOARD OF UNITED ENGINEERING SOCIETY.

Samuel Sheldon, Harold Pender,
Edward D. Adams, W. I. Slichter,
F. L. Hutchinson.

ON ELECTRICAL COMMITTEE OF NATIONAL FIRE PROTECTION ASSOCIATION.

The chairman of the Institute's Code Committee.

ON ADVISORY BOARD OF AMERICAN YEAR-BOOK.

Edward Caldwell.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

W. S. Franklin, G. W. Pierce.

ON CONFERENCE COMMITTEE OF NATIONAL ENGINEERING SOCIETIES.

Calvert Townley, William McClellan,
John J. Carty.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

Charles F. Scott, Samuel Sheldon.

ON NATIONAL JOINT COMMITTEE ON OVERHEAD AND UNDERGROUND LINE CONSTRUCTION.

Farley Osgood, F. B. H. Paine,
Percy H. Thomas.

ON JOINT NATIONAL COMMITTEE ON ELECTROLYSIS.

Bion J. Arnold, F. N. Waterman,
Paul Winsor.

ON U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ILLUMINATION COMMISSION.

A. E. Kennelly, C. O. Mailloux,
Clayton H. Sharp.

ON JOINT COMMITTEE ON CLASSIFICATION OF TECHNICAL LITERATURE.

F. B. Jewett.

ON ENGINEERING FOUNDATION BOARD.

Michael I. Pupin.

ON NAVAL CONSULTING BOARD.

Benjamin G. Lamme, Frank J. Sprague.

ON PAN-AMERICAN ENGINEERING COMMITTEE.

Gano Dunn, William McClellan,
John H. Finney, Charles W. Stone.
Calvert Townley.

ON JOINT COMMITTEE ON METRIC SYSTEMS.

A. E. Kennelly, H. G. Stott.

LOCAL HONORARY SECRETARIES.

Guido Semenza, N. 10 Via S. Radegonda, Milan, Italy.
Robert Julian Scott, Christchurch, New Zealand.
T. P. Strickland, N. S. W. Government Railways, Sydney, N. S. W.
W. G. T. Goodman, Adelaide, South Australia.
James S. Fitzmaurice, Perth, West Australia.
L. A. Herdt, McGill Univ., Montreal, Que.
Henry Graftio, Petrograd, Russia.
Richard O. Heinrich, Genest-str. 5, Schoeneberg, Berlin, Germany.
A. S. Garfield, 45 Boulevard Beausejour Paris, 16 E., France.
Harry Parker Gibbs, Tata Hydroelectric Power Supply Co., Ltd., Bombay, India.
John W. Kirkland, Johannesburg, South Africa.

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LIST OF SECTIONS

Revised to October 1, 1916.

Name and when Organized	Chairman	Secretary
Atlanta.....Jan. 19, '04	A. M. Schoen	H.E.Bussey,3d Nat. Bk. Bldg. Atlanta,Ga.
Baltimore.....Dec. 16, '04	J. B. Whitehead	L.M.Potts,Industrial Bldg.,Baltimore,Md.
Boston.....Feb. 13, '03	Geo. A. Burnham	Ira M.Cushing,84 State St.,Boston,Mass.
Chicago.....1893	Taliaferro Milton	W. J. Crumpton, 111 W. Monroe St. Chicago, Ill.
Cleveland.....Sept. 27, '07	E. W. P. Smith	Bruce W. David, Lincoln Electric Co., Cleveland, Ohio.
Denver.....May 18, '15	H. S. Sands	Robert B. Bonney, Mountain States Tel. and Tel. Co., Denver, Colo.
Detroit-Ann Arbor.....Jan. 13, '11	A. A. Meyer	A. Oakes, American Electrical Heater Company, Detroit, Mich.
Fort Wayne.....Aug. 14, '08	J. J. Kline	
Indianapolis-Lafayette..Jan. 12, '12	J. L. Wayne, 3rd	Walter A. Black, 3042 Graceland Ave., Indianapolis, Ind.
Ithaca.....Oct. 15, '02	E. L. Nichols	W. G. Catlin, Cornell Univ., Ithaca, N. Y.
Kansas City, Mo......Apr. 14, '16	Gordon Weaver	Glenn O. Brown, Kansas City Elec. Lt. Co., Kansas City, Mo.
Los Angeles.....May 19, '08	R. H. Manahan	Carl E. Johnson, 459 East Third Street, Los Angeles, Cal.
Lynn.....Aug. 22, '11	Gordon Campbell	M. B. Carroll, Gen. Elec. Co., West Lynn, Mass.
Madison.....Jan. 8, '09	F. A. Kartak	L. E. A. Kelso, University of Wisconsin, Madison, Wis.
Mexico.....Dec. 13, '07	F. W. Ells	H. P. Reed, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Milwaukee.....Feb. 11, '10	R. A. Lundquist	Vernon S. Beck, Beck Elec. Const. Co., Minneapolis, Minn.
Minnesota.....Apr. 7, '02	Earl J. Atkinsson	C. W. Markham, Balboa Heights, C. Z.
Panama.....Oct. 10, '13	H. P. Liversidge	W. F. James, 14th Floor, Widener Bldg., Philadelphia, Pa.
Philadelphia.....Feb. 18, '03	G. C. Hecker	F. E. Wynne, W. E. and M. Company, East Pittsburgh, Pa.
Pittsburgh.....Oct. 13, '02	V. E. Goodwin	E. K. Shelton, General Electric Company, Pittsfield, Mass.
Pittsfield.....Mar. 25, '04	Paul Lebenbaum	L. T. Merwin, Northwestern Electric Co., Portland, Ore.
Portland, Ore......May 18, '09	O. W. Bodler	Lucien Buck, 1416 Lake Avenue, Rochester N. Y.
Rochester.....Oct. 9, '14	W. O. Pennell	George McD. Johns, Room 401, City Hall, St. Louis, Mo.
St. Louis.....Jan. 14, '03	J. E. Woodbridge	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
San Francisco.....Dec. 23, '04	C. E. Eveleth	H. L. Andrews, General Electric Company, Schenectady, N. Y.
Schenectady.....Jan. 26, '03	C. E. Magnusson	C. F. Terrell, Puget Sound Trac. Lt. and Power Co., Seattle, Wash.
Seattle.....Jan. 19, '04	D. F. Henderson	C. M. Fisher, Washington Water Power Company, Spokane, Wash.
Spokane.....Feb. 14, '13	W. E. Richards	Max Neuber, Cohen, Freidlander & Martin, Toledo, Ohio.
Toledo.....June 3, '07	E. T. J. Brandon	Wills Maclachlan, 910 Excelsior Life Building, Toronto, Ont.
Toronto.....Sept. 30, '03	I. W. Fisk.	L. V. James, Univ. of Illinois, Urbana, Ill.
Urbana.....Nov. 25, '02	R. F. Hayward	T. H. Crosby, Canadian Westinghouse Co., Vancouver, B. C.
Vancouver.....Aug. 22, '11	Arthur Dunlop	Louis G. Freeman, U. S. Geological Survey, Washington, D. C.
Washington, D.C......Apr. 9, '03		

LIST OF BRANCHES

Total 33

Name and when Organized	Chairman	Secretary
Agricultural and Mech. College of Texas.....Nov. 12, '09	A. Dickie	G. B. Hanson.
Alabama, Univ. of.....Dec. 11, '14	Gustav Wittig	A. F. Frazier, University, Ala.
Arkansas, Univ. of.....Mar. 25, '04	A. L. Wilson	W. L. Teague, University of Arkansas, Fayetteville, Ark.
Armour Institute.....Feb. 26, '04	Ralph H. Earle	Harold A. Kleinman, 7743 Burnham Avenue, Chicago, Ill.
Brooklyn Poly. Inst......Jan. 14, '16	AlbertH.Bernhard	Walter J. Secley, The Polytechnic Institute, Brooklyn, N. Y.
Bucknell University....May 17, '10	N. J. Rehman	E. C. Hageman, Bucknell University, Lewisburg, Pa.
California, Univ. of.....Feb. 9, '12	Marc Holzer	C. Maynard, University of California, Berkeley, Cal.
Carnegie Inst. of Tech..May 18, '15	D. L. Trautman	D. F. Gibson, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of.....Apr. 10, '08	C. A. Powell	N. V. McCormick, 3110 Woodburn Ave., Cincinnati, Ohio.
Clarkson Col. of Tech...Dec. 10, '15	W. A. Dart	C. J. Dresser, Clarkson College of Technology, Potsdam, N. Y.
Clemson Agricultural Col. Nov. 8, '12	D. H. Banks	W. H. Neil, Clemson College, S. C.
Colorado State Agricultural College.....Feb. 11, '10	George L. Paxton	Charles F. Shipman, Colorado State Agricultural College, Fort Collins, Colo.

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LIST OF BRANCHES—Continued.

Name and when Organized	Chairman	Secretary
Colorado, Univ. of.....Dec. 16, '04	Charles C. Clymer	Victor E. Leroy, University of Colorado, Boulder, Colo.
Georgia School of Technology.....June 25, '14	C. R. Brown	J. E. Thompson, Georgia School of Technology, Atlanta, Ga.
Highland Park College..Oct. 11, '12	Carl Von Lindeman	C. F. Wright, Highland Park College, Des Moines, Iowa.
Idaho, Univ. of.....June 25, '14	E. R. Hawkins	C. L. Rea, Univ. of Idaho, Moscow, Idaho.
Iowa State College.....Apr. 15, '03	F. H. Hollister	F. A. Robbins, Iowa St. Col., Ames, Iowa.
Iowa, Univ. of.....May 18, '09	H. W. Matson	A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col...Jan. 10, '08	Walter E. Deal	G. B. McNair, Kansas State Agri. Col., Manhattan, Kansas.
Kansas, Univ. of.....Mar. 18, '08	N. M. Foster	G. M. Bowman, University of Kansas, Lawrence, Kansas.
Kentucky, State Univ. of Oct. 14, '10	H. E. Melton	Margaret Ingels, 251 Delmar Avenue, Lexington, Ky.
Lafayette College.....Apr. 5, '12	Samuel McC. Hunt	Carl Theodore Mack, 418 McCartney Street, Easton, Pa.
Lehigh University.....Oct. 15, '02	F. L. Magee	J. F. Wentz, Lehigh University, South Bethlehem, Pa.
Lewis Institute.....Nov. 8, '07	P. B. Woodworth	
Maine, Univ. of.....Dec. 26, '06	Fred P. Jones	G. K. Wadlin, Lambda Chi Alpha House, Orono, Maine.
Michigan, Univ. of.....Mar. 25, '04	A. N. Clarke	F. E. Richardson, University of Michigan, Ann Arbor, Mich.
Minnesota, Univ. of....May 16, '16	Jesse L. Thompson	Donald P. Loye, 4216 Dupont Ave., South Minneapolis, Minn.
Missouri Univ. of.....Jan. 10, '03	K. Atkinson	A. C. Lanier, University of Missouri, Columbia, Mo.
Montana State Col.....May 21, '07	Taylor Lescher	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of.....Apr. 10, '08	Olin J. Ferguson	V. L. Hollister, Station A., Lincoln, Nebr.
North Carolina Col. of Agr., and Mech. Arts.....Feb. 11, '10	F. E. Coxe	R. M. Hooper, N. C. Coll. of A. and M. Arts, West Raleigh, N. C.
North Carolina, Univ. of.Oct. 9, '14	Edw. Y. Keesler	W. H. Joyner, Univ. of North Carolina, Chapel Hill, N. C.
Norwich University.....June 28, '16		
Ohio Northern Univ.....Feb. 9, '12	H. H. Robinson	L. W. Birch, 138 Wheatland Avenue, Columbus, Ohio.
Ohio State University....Dec. 20, '02	H. D. Bender	D. A. Dickey, Ohio State University, Columbus, Ohio.
Oklahoma Agricultural and Mech. Col.....Oct. 13, '11	G. E. Davis	W. C. Lane, Oklahoma A. and M. College, Stillwater, Okla.
Oklahoma, Univ. of.....Oct. 11, '12	H. M. Richards	R. E. Heffner, University of Oklahoma, Norman, Okla.
Oregon Agr. Col.....Mar. 24, '08	Winfield Eckley	J. A. Hooper, Oregon Agri. College, Corvallis, Ore.
Penn. State College....Dec. 20, '02	G. Geracimos	August Heine, State College, Pa.
Pittsburgh, Univ. of....Feb. 26, '14	G. R. Patterson	W. K. Benz, University of Pittsburgh, Pittsburgh, Pa.
Purdue University.....Jan. 26, '03	C. F. Harding	A. N. Topping, Purdue Univ., Lafayette, Indiana.
Rensselaer Poly. Inst...Nov. 12, '09	W. J. Williams	W. R. Townsend, Jr., Rensselaer Polytechnic Institute, Troy, N. Y.
Rose Polytechnic Inst...Nov. 10, '11	H. E. Smock	Sam P. Stone, 1012 North 8th Street, Terre Haute, Ind.
Rhode Island State Col.Mar. 14, '13	C. E. Seifert	Frank A. Faron, Rhode Island State College, Kingston, R. I.
Stanford Univ.....Dec. 13, '07	H. J. Rathbun	J. A. Shepard, Stanford University, Cal.
Syracuse Univ.....Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.....Feb. 14, '08	J. M. Bryant	J. A. Correll, Univ. of Texas, Austin, Tex.
Throop College of Technology.....Oct. 14, '10	J. W. DuMond	K.W. Rich, Throop College of Technology, Pasadena, Cal.
Virginia Polytechnic Institute.....Jan. 8, '15	V. Dixon	John D. Hindle, Virginia Polytechnic Institute, Blacksburg, Va.
Virginia, Univ. of.....Feb. 9, '12	W. S. Rodman	J.H. Moore, Dawsons Row, University, Va.
Wash, State Col. of.....Dec. 13, '07	M. K. Akers	F. V. Carpenter, State Col. of Wash., Pullman, Wash.
Washington Univ.....Feb. 6, '04	Charles A. Lieber	R. W. Macdonald, Washington University, St. Louis, Mo.
Washington, Univ. of...Dec. 13, '12	A. Kalin	J. R. Himmelsbach, 4629 21st Avenue, Seattle, Wash.
West Virginia Univ.....Nov. 13, '14	C. R. Huffman	H. S. McLaughlin, West Virginia University, Morgantown, W. Va.
Worcester Poly. Inst....Mar. 25, '04	C. W. Kennedy	J. A. Blair, Worcester Polytechnic Institute Worcester, Mass.
Yale University.....Oct. 13, '11	A. W. Cahoon	J. P. Allen, Sheffield Scientific School, New Haven, Conn.

Total 56.

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American Institute of Electrical Engineers

ESTABLISHED 1884

PROCEEDINGS

Vol. XXXV **NOVEMBER, 1916** **Number 11**

MEETING IN NEW YORK, NOVEMBER 10, 1916

The 326th meeting of the American Institute of Electrical Engineers will be held in the Engineering Societies Building, 33 West 39th Street, New York, Friday, November 10, 1916, at 8:15 p. m.

The program for the meeting has been prepared by the Committee on Economics of Electric Service and consists of a topical discussion on the subject of

INVENTORIES AND APPRAISALS

The discussion will be introduced by three papers as follows: *The Effect of Recent Decisions on the Work of Inventory and Appraisal*, by Philander Betts, Ph.D., Chief Engineer, Public Utility Commission of New Jersey; *Continuous Inventories; Their Preparation and Value*, by Harry E. Carver, A B., M.E., Assistant Engineer, Public Utility Commission of New Jersey; *Growth and Depreciation*, by Julian Loebenstein, E.E., Junior Electrical Engineer, Public Service Commission of New York, 1st District.

These papers are published elsewhere in this issue of the PROCEEDINGS.

Among those who will take part in the discussion are:

Dr. Frank H. Sommer, Dean of the Law School, New York University. Formerly Counsel to the Public Utility Commission of New Jersey.

Nicholas S. Hill, Jr., Consulting engineer, New York.

Dr. William McClellan, Consulting Engineer. Dean of the Wharton School of Finance, University of Pennsylvania

William B. Jackson, Consulting Engineer, Chicago and Boston

George W. Whitemore, Chief Engineer in charge of cases involving rate investigations for the New York Telephone Company and associated companies.

INSTITUTE MEETING IN BOSTON DECEMBER 8, 1916

The 327th meeting of the American Institute of Electrical Engineers will be held in Boston, Mass., December 8, 1916.

There will be an afternoon and an evening session. The afternoon session will be devoted to papers and discussions on the general subject of "The Standardization of Circuit Breakers with Regard to Their Rupturing Capacity." The principal feature of the evening session will be the presentation of the John Fritz Medal, which has been awarded to Dr. Elihu Thomson. As members of various engineering societies will be present, it is planned to conclude the evening session with a lecture on some subject which will be of general interest.

A. I. E. E. DIRECTORS' MEETING PHILADELPHIA, PA., OCTOBER 13, 1916

The regular monthly meeting of the Board of Directors was held at the Union League Club, Philadelphia, on Friday, October 13, 1916, at 10:30 a. m.

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There were present: President H. W. Buck, New York; Past Presidents Paul M. Lincoln, Pittsburgh, Pa., John J. Carty, New York; Vice-Presidents, C. A. Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., William McClellan, New York, B. A. Behrend, Boston, Mass., P. Junkersfeld, Chicago, Ill., L. T. Robinson, Schenectady, N. Y.; Managers Frederick Bedell, Ithaca, N. Y., A. S. McAllister, New York, John H. Finney, Washington, D. C., C. E. Skinner, Pittsburgh, Pa., John B. Taylor, Schenectady, N. Y., Harold Pender, Philadelphia, Pa., Charles S. Ruffner, St. Louis, Mo., Charles Robbins, Pittsburgh, Pa., N. A. Carle, Newark, N. J.; Treasurer, George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The Secretary announced additional committee appointments made by the President since the Auguts meeting, all of which are included in the lists in this issue.

The Secretary also announced the following appointments upon the Edison Medal Committee, which, in accordance with the by-laws of the committee, were confirmed by the Board:

For the term of five years ending July 31, 1921, Messrs W. C. L. Eglin, Bancroft Gherardi, E. W. Rice, Jr.

To fill the unexpired term of William Stanley, deceased, ending July 31, 1919, Mr. C. C. Chesney.

As chairman of the committee to succeed Dr. S. S. Wheeler, whose term as a member of the committee had expired, Dr. A. E. Kennelly.

The action of the Finance Committee in approving monthly bills amounting to $10,465.84, was ratified.

The report of the Finance Committee submitting the annual budget covering the estimated expenditures of the Institute during the appropriation year beginning October 1, 1916, amounting to $110,100.00, was approved, and the budget was adopted.

The report of the Board of Examiners of its meeting held on October 5 was read, and the actions taken at that meeting were approved.

Upon the recommendation of the Board of Examiners 21 students were ordered enrolled, 76 applicants were elected as Associates, and 10 applicants were transferred to the grade of Member.

Upon request of the Committee on Use of Electricity in Marine Work, the name of the committee was changed to Marine Committee.

A similar request from the Committee on Electricity for Industrial and Domestic Use was granted, the name being changed to Industrial and Domestic Power Committee.

A considerable amount of other business was transacted by the Board, reference to which will be found under appropriate headings in this and future issues of the PROCEEDINGS.

A. I. E. E. PHILADELPHIA MEETING, OCTOBER 13, 1916

The 325th meeting of the A. I. E. E. was held at the Bellevue Stratford Hotel, Philadelphia, October 13th, under the auspices of the Philadelphia Section and the Power Stations Committee of the Institute, and the meeting proved a pronounced success. The total registration numbered 333, of which 192 were local members and 141 visiting members from out of town. The date of the meeting was fixed so that members in attendance at the railway convention in Atlantic City could conveniently attend the meeting in Philadelphia.

In addition to the technical sessions there was a number of committee meetings and a Board of Directors meeting held in Philadelphia, as follows:

Finance Committee meeting Thursday evening at 7 p. m. following a dinner at the University Club.

Standards Committee meeting at the Bellevue Stratford Hotel, Friday, at 9:00 a. m. and again at 4:30 p. m. following the close of the afternoon technical session.

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The Industrial and Domestic Power Committee meeting at the Bellevue Stratford Hotel at 10:00 a. m.

The Board of Directors meeting at the Union League Club, Friday, at 10:00 a. m., and luncheon at the Club at 1:00 p. m. as guests of Vice-President J. Franklin Stevens.

The Lighting and Illumination Committee meeting at the Bellevue Stratford Hotel at 10:30 a. m.

The Power Stations Committee meeting at 11:00 a. m.

The Membership Committee meeting at the Engineers Club at 10:00 a. m.

The Traction and Transportation Committee at the Bellevue Stratford at 4:30 p. m., and the Meetings and Papers Committee at the Engineers Club, Saturday, at 10:00 a. m.

The afternoon technical session was called to order at 2:00 p. m. in the Clover Room of the Bellevue Stratford Hotel by President H. W. Buck, who in opening the meeting stated that considerable scepticism had been expressed that if meetings were held away from the attractions of New York City they would not be successful, and that the proposition to hold Board meetings and Committee meetings away from New York would be impossible as a large number would not attend. In answer to this President Buck stated that the Board meeting in Philadelphia was one of the largest Board meetings ever held in the history of the Institute and the attendance at the technical sessions was a good disproof of the statement that men would not attend the meetings outside of New York. President Buck expressed the opinion that holding meetings for the benefit of men in other cities, who do not make a practise of attending the New York monthly meetings and the annual convention, was highly desirable and that men who have not been heard before will take part in the discussions and thereby enrich our TRANSACTIONS correspondingly.

President Buck then called upon Mr. Eglin to present the first paper of the session entitled "The Power Company's Problem in the Electric Supply for Large Single-Phase Loads"; this was followed by the presentation of the second paper by Mr. Torchio on "Supply of Single-Phase Loads from Central Stations." The two papers were discussed together and the discussion was chiefly along operating lines in regard to methods of furnishing single-phase energy and maintaining proper load balance on a polyphase system. The use of motor generator sets, phase balance s and increasing the size of generator units to supply single phase load were discussed at considerable length.

The afternoon session adjourned at 4 p. m., and previous to adjournment Mr. Eglin announced that the new phase balancers described in his paper were in operation at the station of the Philadelphia Electric Company and issued a general invitation to all to visit the station and see them in operation. A large number of those present subsequently paid a visit to the station to see the new machines.

At 6 o'clock an informal dinner was held in the Stratford Room of the Bellevue-Stratford Hotel. This dinner was largely attended, the room being filled to its capacity.

Mr. H. P. Liversidge, Chairman of the Philadelphia Section acted as toastmaster and some brief remarks were made by President Buck, Mr. Farley Osgood and Vice-President P. Junkersfeld.

At the close of the speaking the technical session reconvened in the Clover Room of the hotel. The session was opened by the presentation by E. F. W. Alexanderson of a paper on "Single-Phase Power Production" by himself and Mr. G. H. Hill. This was followed by the paper "Single-Phase Power Service from Central Stations" by R. E. Gilman and C. L. Fortescue, and was read by Mr. Fortescue. The discussion of these two papers continued until 11 o'clock, and was largely along the lines of cost of manufacture of the

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different devices for supplying single-phase energy from polyphase generators.

Before adjournment a vote of thanks was given to the authors of the papers and to the members and officers of the Philadelphia Section for their very hospitable reception and their satisfactory provision for the meeting.

INSPECTION TRIP TO SUBMARINE BASE AT NEW LONDON, CONN.

In view of the general interest in submarines at this time, the American Society of Mechanical Engineers has organized a joint section meeting to visit the plant of the Electric Boat Company at New London, Conn., on Saturday afternoon, November 11. Members of the American Institute of Electrical Engineers as well as a number of other engineering societies, clubs, and technical schools have been cordially invited to participate in this meeting. Some of the largest and best Diesel engines produced in this country have been built in this plant, and there will be a special test of a high power 8-cylinder, 4-cycle engine. A large number of submarine and other engines in various stages of construction will be seen, also the boring of torpedo tubes, cylinders and other equipment for submarines. The drafting rooms and foundry will also be open for inspection. The visitors will have an opportunity to witness a special exhibition by several submarines. The Submarine Base and Training School is located near New London.

Visitors from Boston will leave the South Station, Saturday morning, November 11, on Train No. 7 at 8:30 a. m.

Those from New York will leave the Grand Central Terminal at 8:31 a. m. on Train No. 8.

Upon arrival at New London visitors will go directly to the Mohican Hotel where luncheon will be served promptly at 11:45 so that the party can leave for the plant of the Electric Boat Company promptly at 1:00 p. m. The trip through the plant will require about 1½ hours.

The party will then return to the ferry boat and go out into the Sound to witness the submarine exhibit by three or four submarines which will be arranged by courtesy of Rear Admiral A. W. Grant who is in command of the submarine forces of the United States. The visitors will have an opportunity to see at close range the submerging of a submarine and an attack on a vessel on the surface.

Expenses from New York City

If 300 people or more go from New York City the railroad excursion fare and luncheon will cost not over $5.00. If less than 300 go from New York the reduced railroad fare cannot be obtained, making the railroad fare and luncheon cost $7.25. In order to obtain the minimum rate it will be necessary to know by November 4th how many will make the trip. Those intending to go should notify the A. S. M. E. promptly. Ladies and non-members are welcome.

LECTURE ON SUBMARINES

In addition to the inspection trip described above the A. S. M. E. has arranged for a lecture on "Submarines" by Mr. Charles H. Bedell, electrical engineer of the Electric Boat Company. The lecture will be given in the auditorium of the Engineering Societies Building on Tuesday, November 14, 1916, at 8:15 p. m. Members of the A. I. E. E. are cordially invited to attend this lecture.

PAST SECTION MEETINGS

Denver.—September 28, 1916, Denver Athletic Club. Meeting in honor of Honorary Secretary Ralph W. Pope. Luncheon served at 12:15 p. m., after which Mr. Pope gave an address on "The History of Section Development." Attendance 21.

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Panama.—October 3, 1916, Gatun Hydroelectric Station. Major W. H. Rose gave an address on "New Plans for the Power System of the Panama Canal." Attendance 71.

Rochester.—September 22, 1916, Engineering Society Rooms. Paper: "Some Little-Recognized Factors in Power-Limiting Reactors," by John C. Parker. Attendance 60.

San Francisco.—September 24, 1916, Engineers Club. Papers; (1) "The Entz Transmission," by H. S. Clarrager; (2) "Electric Starting, Lighting and Ignition as Applied to the Automobile," by H. A. Hussey. Attendance 78.

Schenectady.—October 6, 1916, Edison Club Hall. Address by Mr. E. W. Rice, Jr., on "The Engineer's Duty toward Civilization." Attendance 450.

St. Louis.—October 11th, 1916, Engineers' Club. Illustrated address by Prof. A. S. Langsdorf on "The Opportunities Offered by Washington University." Attendance 44.

Toledo.—October 6, 1916, Toledo Commerce Club. Paper: "Central Station Power for Steel Mills," by J. W. Kunz. Report on the Annual Convention of the A.I.E.E. by Mr. M. E. Grah. Attendance 21.

PAST BRANCH MEETINGS

Armour Institute.—October 5, 1916, Prof. Freeman gave an explanation of the purposes and benefits of the A.I.E.E. in general and of the Armour Branch in particular. Attendance 40.

Brooklyn Polytechnic Institute.—October 9, 1916, Mailloux Library of Electrical Engineering. Address by Dr. Samuel Sheldon on "Success and Its Achievement." Attendance 64.

University of California.—September 6, 1916. Paper: "The Effect of a Lagging Power Factor on an Alternating Generator," by Mr. Holzer. Attendance 11.

September 20, 1916. Paper: "The Small Isolated Hydroelectric Plant," by Mr. Nudd.

Colorado State Agricultural College.—October 2, 1916, Electrical Hall. Election of officers as follows—president, Howard W. McKinley; secretary, F. G. Stiers.

Iowa State College.—September 20, 1916. Election of officers as follows—chairman, C. I. Merrick; recording secretary, L. W. Coquillette; corresponding secretary, F. A. Robbins; treasurer, Victor Kelley. Attendance 28.

October 4, 1916. Paper: "A Survey of a Water Power Site," by A. F. Soukup. Attendance 31.

University of Kansas.—September 27, 1916, Marvin Hall. Address by Prof. Geo. C. Shaad on "The Meaning of the A.I.E.E." Prof. H. M. Curfman told of his experiences in the testing laboratories of the General Electric Company. Attendance 80.

University of Maine.—October 12, 1916, Hannibal Hamlin Hall. Addresses by Professor Barrows and Mr. Harvey. Attendance 69.

Montana State College.—September 22, 1916, Electrical Building. Election of officers as follows—chairman, Carl Ladenburg; secretary, J. A. Thaler. Attendance 36.

University of Nebraska.—October 4, 1916, Electrical Engineering Building. Addresses by Prof. Freeman and Messrs. Holtz and Ackerman on the aim and accomplishments of the A.I.E.E. and the local Branch. Attendance 40.

Ohio State University. October 13, 1916, Robinson Laboratory. Address by Prof. Caldwell on "The Organization of the A.I.E.E." Attendance 30.

Stanford University.—September 5, 1916. Paper: "Testing of High-Voltage Insulators," by H. J. Rathbun. Attendance 14.

September 20, 1916. Election of officers as follows—chairman, H. W. Lewis; vice-chairman and librarian, L. S. Kinnear; secretary, A. L. Morgan. Paper: (1) "Replacing the Lightning Conduits and Conductors at Stanford

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University," by M. J. Cody; (2) "Distribution of the Southern Sierras Power Company, with Particular Reference to Outdoor Switches and Transformers," by H. C. Parker. Attendance 12.

October 4, 1916. Paper: "The System of the Sierra and San Francisco Power Company, with Emphasis on Line Construction," by M. T. Rodig. Attendance 11.

Virginia Polytechnic Institute.—October 9, 1916, Election of officers as follows—chairman, J. D. Hindle; vice-chairman, B. McIntosh; secretary-treasurer, E. S. Smithson. Attendance 20.

University of Virginia.—October 3, 1916. Election of officers as follows—chairman, W. S. Rodman; secretary-treasurer, J. K. Peebles. Talks by students on work engaged in during vacation, as follows— (1) "Motor and Insulation Testing," by Mr. Philips; (2) "Survey of Coal Deposits," by P. F. Bown; (3) "Manufacture of Shrapnel Shells," by J. H. Moore. Attendance 15.

University of Washington.—September 26, 1916, Forestry Hall. Professor E. A. Loew gave an address on "Elements of Success for the Engineer," and Dr. C. E. Magnusson spoke on "Interesting Features of the A.I.E.E. Pacific Coast Convention." Attendance 45.

NEW PUBLICATIONS OF THE BUREAU OF STANDARDS

The Bureau of Standards has recently issued Circular No. 60 entitled "Electric Units and Standards." This circular gives comprehensive information in regard to units and standards in terms of which electric and magnetic measurements are made. It gives a history of the units and definition upon which the laws of electrical standards are based. It also gives conversion factors by means of which measurements may be expressed in any desired units.

The Bureau has also published scientific paper No. 285 entitled "Summary of Experiments on the Silver Voltameter and Proposed Specifications." This is the standard instrument by which the international ampere is determined and investigations at the Bureau of Standards have been carried on for the past 8 years during which time results have been published in several papers. This paper contains a summary of previous papers and carefully drawn specifications which are the direct result of the Bureau's work. A bibliography of papers on this subject is also given in an appendix.

Those interested in the above papers may obtain copies free by addressing request to the Bureau of Standards.

RECOMMENDED FOR TRANSFER OCTOBER 5, 1916

The Board of Examiners, at its regular monthly meeting on October 5, 1916, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To the Grade of Fellow

Havill, O. A., Electrical Engineer, Viele, Blackwell & Buck, New York, N. Y.

To the Grade of Member

Carroll, Emil J., Electrical Engineer, American Laundry Machine Co., Cincinnati, O.

Chamberlain, F. G., Vice-President, Tuttle, Chamberlain & Co., San Antonio, Tex.

Gooding, Robert F., Switchboard Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Goodwin, Harold, Jr., Superintendent of Distribution, Philadelphia Electric Co., Philadelphia, Pa.

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HECKER, GUY C., Chief Electrician, Pittsburgh Railways Co., Pittsburgh, Pa.

KENYON, OTIS ALLEN, Engineer, Arc Welding Machine Co., New York, N. Y.

MULRONY, MARION A., Chief Engineer, Shaw Wireless Ltd., Sydney, Australia.

NASH, LUTHER R., Public Utility Expert, Stone & Webster Management Association, Boston, Mass.

STEWART, HAROLD O., Engineer, Industrial Dept., Rochester Railway & Light Co., Rochester, N. Y.

TAYLOR, WILLIAM B., Engineer of Insulation Dept., General Electric Co., Lynn, Mass.

THOMAS, GEORGE B., Professor of Electrical Engineering, Colorado College, Colorado Springs, Colo.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before November 30, 1916.

Bergland, E. L., Wilmington, Del.
Brinkmeier, E. H., St. Louis, Mo.
Carver, H. E. (Member), Newark, N. J.
Cavalcanti, L. de A., East Pittsburgh, Pa.
Cope, H. W. (Member), East Pittsburgh, Pa.
Corney, C. A., Boston, Mass.
Deans, W., Ithaca, N. Y.
Diamant, N. S., Houston, Tex.
Fick, C. W., Schenectady, N. Y.
Foley, J. W. B., Port Arthur, Tex.
Frommelt, H. A., Florissant, Mo.
Ganter, E. L., St. John, N. B.
Gazda, A. A., East Pittsburgh, Pa.
Gerber, L. S. Schenectady, N. Y.
Gould, R., Chico, Cal.
Gratiot, J. T. (Member), Denver, Colo.
Hanff, E. A., Irwin, Pa.
Hartenstein, H. (Member), Havana, Cuba.
Holtz, F. C., Lincoln, Neb.
Huff, E. L., Natrona, Pa.
Hunter, R. B. (Member), Milwaukee, Wis.
Jones, C. R., New York, N. Y.
Jones, E. E., St. Louis, Mo.
Jones, R. A. New York, N. Y.
Kile, R. B., Pittsburgh ,Pa.
Kirk, R. L., Pittsburgh, Pa.
Kivlin, A. P., Newark, N. J.
Leedorn, R., New York, N. Y.
Lindsey, J. K., Akron, O.
Lyle, J. W., Hillsboro, Tex.
Lytle, J. H., Clearfield, Pa.
Manning, S. R., Detroit, Mich.
Mason, G. E., Toronto, Ont.
McAfee, W. K., East Pittsburgh, Pa.
Moultrop, N. I., Boston Mass.
Nelson, J. M. (Member) New York, N.Y.
Ort, C., New York, N. Y.
Osborne, C. P., Portland, Ore.
Quirk, W. G., New York, N. Y.
Raymond, F. A. (Member), New York, N. Y.
Robertson, F. J., Seebe, Alta.
Shaw, A. M. T., Philadelphia, Pa.
Simpson, A. R., New York, N. Y.
Smith, L. M., Ensley, Ala.
Smith, R. W., Columbus, Ga.
Srinivasayengar, V. K., Hubli, India
Stein, S., New York, N. Y.
Sturz, F., Jr., New York, N. Y.
Tremaine, A. R., Lancaster, N. Y.
Trinkle, R. J., Hopewell, Va.
Walters, D. G., New York, N. Y.
Wei, W. L., Schenectady, N. Y.
Weller, F. R., West Orange, N. J.
Wells, J. H., Brooklyn, N. Y.
Whaler, H. T., Miami, Fla.
Whately, H. E., Toronto, Ont.
Wheadon, F. W. H., Adelaide, S. Aus.
Williams, E. P., Fredericton, N. B.
Wiseman, R. J., Boston, Mass.
Wolff, A. F., Spokane, Wash.
Total 60

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ASSOCIATES ELECTED OCTOBER 13, 1916

*ANDREWS, HARDAGE LANE, Engineer, Railway and Traction Dept., General Electric Co.; res., 209 Seward Place, Schenectady, N. Y.

BAER, LOUIS EDWARD, Transportation Dept., Twin City Rapid Transit Co.; res., 1370 Thomas St., St. Paul, Minn.

BARNUM, WARD, Senior Electrical Engineer, Interstate Commerce Commission, Municipal Building, Chattanooga, Tenn.

BEAR, S. LEE, General Engineering Div., Westinghouse Elec. & Mfg. Co, E. Pittsburgh, Pa.

*BOWLER, SAMUEL EDWARD. General Foreman of Construction, Stone & Webster Engineering Corp., 8 Waverly Bldg.; res., 66 Capital Ave., Hartford, Conn.

BUELL, FREDERICK ALLEN, Junior Electrical Engineer, Interstate Commerce Commission, Interstate Bldg., Kansas City, Mo.

CHURCHILL, BENJAMIN FRANKLIN, Telephone Wire Chief, Mountain States Telephone and Telegraph Co.; res., 51 W. Alameda Ave., Denver, Colo.

COWLES, C. C., Electrical Expert Aid, Puget Sound Navy Yard; res., 919½ Highland Ave., Bremerton, Wash.

COX, WILLIAM NORRISS, Local Engineer, General Electric Co., 1218 Munsey Building, Baltimore, Md.

CURTIN, WILLIAM ERNEST, Railway Motor Dept., General Electric Co.; res., 69 Allen St., Lynn, Mass.

DE WYAALL, OSCAR EDWARD, Engineering Dept., Gould Storage Battery Co., New York, N. Y.; res., Ridgefield Park, N. J.

DUFF, SIDNEY S., General Foreman, Montana Power Co., Gold Creek, Mont.

FERGUSON, HOWARD F., Supt. of Power, West Penn Power Co., Benedum-Trees Bldg.; res., 6205 Alder St., Pittsburgh, Pa.

*FINK, HENRY, JR., Master Mechanic, San Antonio Traction Co. and San Antonio Gas and Electric Co.; res., 323 Goliad St., San Antonio, Tex.

FISHER, ELMO HERMAN. In Charge of Steam and Electricity, Pittsburgh Div., Pittsburgh & Lake Erie Railroad, Pittsburgh; res., 224 Hawkins Ave., N. Braddock, Pa.

*FLOYD, FAY N., Draftsman-Engineer, Trinidad Electric Transmission, Railway & Gas Co.; res., 630 Willow St., Trinidad, Colo.

FRANKLIN, CHARLES W., Cadet Engineer, New York Edison Company.; res., 3544 Broadway, New York, N. Y.

*GAILUNAS, JOHN PAUL, Operating Engineer, Engineering Dept., Statler Hotel; res., 1442 W. Grand Blvd., Detroit, Mich.

GARDNER, LESTER HOKE, Consulting Engineer, Emerson-Brantingham Co., 2723 University Ave. S. E.; res., 3305 Garfield Ave. S., Minneapolis, Minn.

GEREND, MATTHIAS STEPHEN, Foreman of Pumping Plant, Reclamation District 1500, Grafton, Cal.

GOODING, ROBERT FLEMING, Switchboard Engineer, Westinghouse Electric & Mfg. Co., East Pittsburgh; res., 529 Coal St., Wilkinsburg, Pa.

*GRAY, FRED JAY, Inspection Dept., Electrical Testing Laboratories; res., 624 W. 182nd St., New York, N. Y.

GRIGSBY, BERTRAM JAMES, Managing Director, Benjamin Electric, Ltd., 1a Rosebery Ave., London, E. C., England.

HENRY, LEWIS WARNER, Superintendent of Construction, Knoxville Power Co., Alcoa, Blount Co., Tenn.

*HOLMES, ALBERT, Public Utility Section, Electrical Division, Bureau of Standards; res., 5406 Colorado Ave., Washington, D. C.

HONAMAN, RICHARD KARL, Teacher, Dept. of Physics and Mathematics, Franklin and Marshall College; res., 310 W. Lemon St., Lancaster, Pa.

HURD, SYDNEY JOHN, Checker of Overhead Electrical Inventory, Sanderson & Porter; res., 2379 Milwaukee Ave., Chicago, Ill.

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*JONES, CARL G., Transformer Engineer, Kuhlman Electric Co.; res., 1110-4th Ave., Bay City, Mich.

KERRIGAN, ARTHUR JOHN, Efficiency Work, Saco-Lowell Shops; res., 1 Litchfield Terrace, Lowell, Mass.

KIRKPATRICK, EDWARD MARSHALL, Testing Dept., General Electric Co., 81 Park St., West Lynn, Mass.

LAURENSON, JAMES SIMON, Switchboard Attendant, Government Railway Works; res., Limestone St., Ipswich, Queensland, Australia.

MACLOON, ERNEST HENRY, Superintendent, Lyman Falls Power Co., Groveton, N. H.

MAXWELL, FREDERICK RICHARD, JR., Commercial Manager, Tuscaloosa Railway & Utilities Co.; res., 2703-6th St., Tuscaloosa, Ala.

*MCCLURE, DONALD COLLIER, Electrical Engineer, Denver Gas and Electric Light Co.; res., 178 So. Humboldt St., Denver, Colo.

METZ, EARLE CALVIN, Naval Officer, U. S. Navy Department, Washington, D. C.

MORI, HYOGO, Assistant Professor of Electrical Engineering, Imperial Kyushu University, Fukuoka, Japan.

NEFF, CHARLES CLEVELAND, Chief Electrician, Pittsburgh-Belmont Coal Co., Neffs; res., Steel, Ohio.

NELSON, ARTHUR LINDSAY, Asst. Electrical Engineer, Charles H. Tenney & Co., Boston; res., 30 Mellen St., Ashmont, Mass.

NORMAN, C. L., Electrical Contractor, 314 Oakland Bank of Savings; res., 9 Moss Ave., Oakland, Cal.

OLIVER, CLIFFORD, General Electric Co.; res., 732 Brandywine Ave., Schenectady, N. Y.

*OLMSTED, CHANCY STEPHAN, Assistant Electrical Engineer, Detail Design Dept., Chile Exploration Co.; res., 211 W. 117th St., New York, N. Y.

O'RYAN, FRANK, Salesman, Allis-Chalmers Mfg. Co., First National Bank Bldg. Denver, Colo.

OWEN, NATHANIEL J., Control House Operator, Panama Canal, Pedro Miguel, Canal Zone.

PARKER, RAYMOND WEBB, Cadet Engineer St. Clair County Gas & Electric Co.; res., 609 S. Jackson St., Belleville, Ill.

PHILIP, HERBERT ARTHUR, Engineer, Service Dept., Westinghouse Electric & Mfg. Co., 512 W. 23rd St.; res., 2512 University Ave., New York, N. Y.

PHILLIPS-WATTS, JAMES, Switchboard Operator, Sub-stations, West Kootenay Light & Power Co. Ltd.; res., Arlington Hotel, Trail, B. C.

PLOWMAN, ASHLEY SHERIDAN, Teacher of Physics and Electrical Engineering, Technical College, Broken Hill, N. S. W., Australia.

REGAL, ALVIN PAUL, Electrical Engineer, Philadelphia Rubber Works Co.; res., 819 Crosby St., Akron, Ohio.

RETT, CARL E., Electrical Draftsman, Firestone Tire & Rubber Co.; res., 895 S. Main St., Akron, Ohio.

REUBEN, JOHN SAMUEL, Chief Assistant, Anglo-American Electric Stores; res., 13 Wood St., Bangalore, India.

ROBERTS, CARROL BRENT, Sales Engineer, Standard Electric & Elevator Co., 123 S. Calvert St.; res., 1609 E. Preston St., Baltimore, Md.

ROBERTS, THEODORE CHARLES, Chief Engineer, United Verde Copper Co., United Verde & Pacific Railway Co., Clarkdale; res., Jerome, Ariz.

ROBINSON, EDMUND, Inspector, Boston Edison Co., Boston; res., 22 Highland Ave., Melrose Highlands, Mass.

ROBINSON, ROYAL WILBUR, Electrician, Universal Film Co., Universal City; res., 221 E. Ave. 40, Los Angeles, Cal.

ROWLANDS, RICHARD A., Meter and Transformer Specialist, General Electric Co., 410-3rd Ave. N., Minneapolis, Minn.

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RUSSELL, FLOYD LESTER, Engineering Assistant, Public Service Electric Co.; res., 44 Bleecker St., Newark, N. J.

SAGE, RUSSELL S., Engineer, Power & Mining Dept., General Electric Co.; res., 702 South Ave., Schenectady, N. Y.

SAND, JAMES HARVEY, Electrical Tester, New York Edison Co., New York; res., 289 9th St., Brooklyn, N. Y.

*SHALLCROSS, SAMUEL M., Transformer Designer, Westinghouse Electric & Mfg. Co., East Pittsburgh; res., 411 Rebecca Ave., Wilkinsburg, Pa.

SIMPSON, FRANK, Salesman, Verne W. Shear & Co., 609 Flatiron Building; res., 255 Grand Ave., Akron, Ohio.

SMITH, Harold Wood, Commercial Engineer, Public Service Electric Co., Room 303, Newark, N. J.

SMITH, HERBERT ROLLAND, Electrician, Edison Electric Illuminating Co., Boston; res., 16 Fenno St., Roxbury, Mass.

STAVELY, EARL BAKER, Instructor in Electrical Engineering, Pennsylvania State College, State College, Pa.

STEARNS, CLYDE MELNOT, Equipment Assistant, New England Tel. & Tel. Co., 50 Oliver St., Boston; res., 263 Auburndale Ave., Auburndale, Mass.

*STEINER, LEO ERNEST, Electrician, France Stone Co., Toledo; res., Dunkirk, Ohio.

STIRLING, HARRY H., Test and Meter Work, Electrical Engineering Dept., Tennessee Coal, Iron & R. R. Co., Ensley; res., Adamsville, Ala.

SWIFT, FRANCIS ELMER, Fort Wayne Electric Works; res., 128 Masterson Ave., Fort Wayne, Ind.

*SWITZER, FREDERICK GEORGE, Instructor in charge of Hydraulics, Sibley College, Cornell University; res., 202 Stewart Ave., Ithaca, N. Y.

TALIAFERRO, THOMAS CARSON, Assistant Engineer, South Eastern Underwriters' Association, Atlanta; res., Decatur, Ga.

*THOMAS, JOSEPH EDGE, System Operator, West Penn Power Co., Benedum Trees Bldg., Pittsburgh; res., 200 Franklin Ave., Wilkinsburg, Pa.

VRLA, RUDOLPH ROBERT, Signal Engineer's Apprentice, General Railway Signal Co., New York; res., 345 St. Marks Ave., Brooklyn, N. Y.

*WILKINS, ROY, General Construction Dept., Pacific Gas & Electric Co.; res., 1401 L St., Sacramento, Cal.

WILSON, JOHN SPICER, Special Assistant to Electrical Engineer, E. I. du Pont de Nemours & Co., City Point, Va.

*WILSON, RICHARD MORTON, Engineering Dept., Puget Sound Traction, Light & Power Co.; res., 4720 9th Ave. N. E., Seattle, Wash.

WISEMAN, DANIEL E., Equipment Engineer, Pacific Telephone & Telegraph Co., 622 Sheldon Bldg.; res., 133 Buena Vista Ave., San Francisco, Cal.

YAMATO, SANTARO, Electrical Engineer, Kawasaki Dockyard Co.; res., 143-12, Yabeche, Hirano, Kobe, Japan.

*YAMBERT, DALE WILLIAM, Electrical Engineer, France Stone Co., 2nd National Bank Bldg.; res., 1909 Jefferson Ave., Toledo, Ohio.

Total 77.

*Former enrolled Students.

MEMBERS ELECTED OCTOBER 13, 1916

JONES, CLAUDE ASHTON, Lieutenant U. S. Navy, Chief Engineer, U. S. S. *Memphis*, c/o Postmaster, New York, N. Y.

MAPES, MILTON CRAWFORD, Consulting and Construction Engineering, Westcott and Mapes (Inc.); res., 1245 Chapel St., New Haven, Conn.

RICHARDSON, EARL HOLMES, Secretary, Hotpoint Electric Heating Co.; res., 603 Lemon Ave., Ontario, Cal.

*ROSENBLATT, ARTHUR MORTON, Superintendent, Virginian Power Co., Coalburgh, W. Va.

STEVENS, RAY PARKER, President and Chief Engineer, Mahoning & Shenango Ry. & Lt. Co.; res., 689 Wick Ave., Youngstown, Ohio.

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TRANSFERRED TO THE GRADE OF MEMBER OCTOBER 13, 1916

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on October 13, 1916.

BARFOED, SVEND, Electrical and Hydraulic Engineer, California Power & Mfg. Co., San Francisco, Cal.

BATCHELDER, C. E., Engineer, General Electric Co., Buenos Aires, A. R.

BILLINGS, W. C., Supt., Power and Light Div., Cumberland County Power and Light Co., Portland, Me.

BIXBY, WILLIAM P., Electrical Engineer, Nashville, Chattanooga & St. Louis Railway, Nashville, Tenn.

EAGER, WILLIAM G., Second Vice-President and General Manager, Valdosta Lighting Co., Valdosta, Ga.

FARWELL, STANLEY P., Chief of Service Dept., State Public Utilities Commission of Illinois, Springfield, Ill.

LIPSCOMB, GASTON JOEL, Engineer, W. R. Grace & Co., Iquiqui, Chile.

MCCARTY, FRANCIS ALEXANDER, Consulting Electrical Engineer, Melbourne, Australia.

SINCLAIR, STEPHEN L., Electrical and Mechanical Superintendent, U. S. Reclamation Service, Williston, N.D.

SUMMERHAYES, HENRY R., Assistant Engineer, Lighting Dept., General Electric Co., Schenectady, N. Y.

STUDENTS ENROLLED OCTOBER 13, 1916

8281 Vorlop, E. W., Univ. of Wis.
8282 Schloth, A. C., N. Y. Elec. Sch.
8283 Eastman, H. F., Mass. Inst. Tech.
8284 Steward, W. A., Univ. of Cincinnati.
8285 Kurtz, E. B., Univ. of Wis.
8286 Wood, R., Univ. of Wisconsin
8287 Nethercut, D. M., Univ. of Wis.
8288 Kalin, A., Univ. of Washington
8289 Pelaez, E., Ohio Northern Univ.
8290 Cory, S. I., Ohio State University
8291 Earle, R. H. Armour Inst. of Tech.
8292 Fisher, F. E., Univ. of Washington
8293 Poe, C. R., Univ. of Wisconsin
8294 Barbee, W. L., Univ. of Wash.
8295 Farmer, H. R., N. Y. Elec. School
8296 Faubert, E. H., Univ. of Wash.
8297 Lubcke, C. M., Univ. of Wash.
8298 Snow, G. W., N. Y. Elec. School
8299 Bayle, R. M., Ohio Northern Univ.
8300 Roberts, L. T., N. Y. Elec. Sch.
8301 Dusenbery, H. S., Univ. of Cal.
Total 21

PERSONAL

MR. ALGERNON ROBERTS CHEYNEY, until recently Supt. of Operation of the Philadelphia Electric Company has accepted a position with the Westinghouse Electric and Manufacturing Company of East Pittsburgh as General Engineer.

MR. FORD W. HARRIS, a Fellow of the Institute and a member of the A. S M.E. formerly with the Westinghouse Electric and Manufacturing Company in the capacity of Designing Engineer was on October 5, 1916, admitted to practise law in the State Courts of California.

ACCESSIONS TO LIBRARY

This list includes books on electrical subjects only, which have been added to the library of the A. I. E. E. and the U. E. S. during the past month, not including periodicals and other exchanges.

Competition in Electricity. No. 5. The "Block" heating and Electric Plant. Evidence that groups of buildings under same or different ownership can obtain heat and electricity from one privately owned central utility plant. No. 6—How many New of York's greatest factories are supplied with power from private power plants. No. 7—How many of Chicago's "Notable Buildings" are supplied with electricity from private power plants. (Gift of Charles Meigs Ripley.)

Continuous and Alternating-Current Machinery. By J. H. Morecroft, New York, 1915. (Purchase)

Engineering Applications of Higher Mathematics. By V. Karapetoff. Parts 2-5. New York, J. Wiley & Sons, 1916. (Gift of Publishers) Price $0.75 for each part.

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——Report of examiners of Section XXIX. Educational Apparatus.

New York City. Board of Electrical Control. Second Report 1888.

Peyrusson, E. Electrolyseur et procedes d'electrolyse.

The Poulsen telegraphone.

Report of the special committee on the Static induced current appointed at the 10th annual meeting of the American Electro Therapeutic Asso., Sept. 27, 1900.

Tomasi, D. Electrolytic processes for the extraction, separation and refining of metals. Paris, n. d.

GIFT OF ARTHUR WORISCHEK

Cazin, A. L'Etincelle electrique. Paris, 1876

Lauriol, Jules. Transport electrique de la Force. Les experiences de Creil. Paris, 1886.

Part 1, on Machine Design was published in 1912. The parts now issued give problems in the application of mathematics to hydraulics, thermodynamics, mechanics of material and electrical engineering respectively.

W. P. C.

Principles of the Telephone. Part I—Subscriber's Apparatus. By C. M. Jansky and D. C Faber. New York, 1916. (Purchase)

GIFT OF C. A. DOREMUS

Death from electrical currents.

Gramme's Magneto to Electric Machines.

International Electrical Exhibition, 1884. General Report of the Chairman of the Committee on exhibitions.

EMPLOYMENT DEPARTMENT

Note: Under this heading brief announcements (not more than fifty words in length) of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months: during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

VACANCIES

V-151. Technical Graduate, (E. E.), young, unmarried, with at least one or two years' practical experience, preferably with one of the large manufacturing companies. Work will include a variety of electrical testing and the collection and arranging of electrical operating data. Location, Idaho.

The U. S. Civil Service Commission announces an examination to be held November 14, for expert electrical and mechanical aid, in the Bureau of Yards and Docks, Navy Dept., at $12.48 per diem. Application should be made to the Commission in Washington, D. C., for circular No. 1413, describing the examination and application form No. 1312.

V-169. A New England concern is desirous of securing several progressive young men who have a general knowledge of electric motors and their application, also goods sales records. Kindly give all particulars.

V-180. Wanted: Four technical graduates, having about five years' experience in electrical, metallurgical or chemical lines. Field and office work. Two of the above should be men of tact (sales engineers) who can meet clients. Salary $125 to $150 per month, or more if record warrants. Give full particulars.

MEN AVAILABLE

586. Construction or Maintenance Engineer, with technical education and varied experience in central and substation construction work. Employed at present by large traction and lighting company; willing to go anywhere, West preferred. Formerly with Allis-Chalmers Mfg. Co. Available at short notice. Moderate initial salary with good prospects. Good character; temperate.

587. Graduate Electrical Engineer, experienced in power plant work, both mechanical and electrical, also general business management of enterprises. Familiar with estimating, contracting and reporting for bankers on feasibility of projects. Would consider employment, partnership or moderate investment in good enterprise where banking connection would be useful.

588. Superintendent or Electrical Engineer of light, power or railway

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utility. Has had four years' steam and electric road experience with large manufacturing company, as well as four years' central station work, including high and low tension distribution and construction, meters, testing and operation. Technical graduate, age 30, available December 1.

589. Assistant to Manager or Executive; technical education along electrical and hydraulic lines. Five years' experience with electrical machinery. Five years as assistant to operating electrical engineer. Age 29. Desires to connect with concern in East or South where he can broaden experience.

590. Electrical Engineer, age 38, married, technical education, fourteen years' practical experience in charge of electrical equipment in large cement, steel and glass plants. Safety first, reliability and economy practiced. In present position six years, same too small, desire change. Write for my credentials.

591. Electrical Engineer, Russian, age 30, graduate of Kieff Polytechnical Institute; seven years' experience with Siemens-Schuckert and Siemens-Halske Electrical Co. of Germany and Russia. Specialty—automatic telephony, signalling, electromedicine, X-ray, measuring instruments. Competent to design, test and operate all kinds of electrical machinery. Speaks Russian, German, French and English.

592. Electrical Graduate and Chief Electrician. Present assistant chief electrician of plant with 600 motors, also direct supervision of installation of piping and wiring in ten-floor plant addition. Have had some experience of installation of underground cable work. Prefer position of this character, located near Chicago.

593. Superintendent or Manager, American, Mem. A. I. E. E., married, 32, speaks Spanish and French. Long experience in operation and construction, principally hydroelectric, transmission and distribution; record first class. Will go anywhere in North or South America. In New York after Oct. 15.

594. Manager, graduate engineer, Mem. A. I. E. E., with ten years' experience in all departments of large central station company, desires position as manager or assistant manager of a central station company. Has had experience in construction, operating, billing, metering and industrial power departments. Now employed.

595. Electrical Engineer, now employed, will be available January 1, 1917 Married, age 32. Technical graduate, with four and one-half years' experience on design, construction and operation of power stations, transmission lines and substations. A willing worker.

596. Graduate in engineering and arts, 30, wants to build up or reorganize department or factory. A $3,000 man with six years' success in similar work involving technical and executive ability. In real opportunity can base salary on results.

597. Electrical Engineer, technical graduate, with Westinghouse apprenticeship training, wishes position with electrical contracting firm or utility corporation on construction or appraisal work. At present located in New York City but will go anywhere; South preferred. Salary $1500.

598. Stanford Graduate, now employed as assistant in charge of an office, would like a change to more active work with a chance of advancement. Experience includes four years of active test work and three years in present work, besides considerable mechanical experience. Good on details Location of secondary importance.

599. Hydroelectrical Engineer, age 35, technical graduate. Well informed theoretically, with broad experience in the hydraulic and electrical features of power and irrigation systems. Experience covers designs, specifications, estimates, efficiency testing and construction work. One year in South America; 1½ years on valuation of large power and substations.

600. Electrical Engineer, technical graduate and post-graduate, age 29. Over six years' experience in construction, research, drafting; extensive electrical, steam turbine and power plant testing; also design of rotary converters and power plants. Prefer position which requires executive ability. At present employed in the East; will go anywhere.

601. Electrical Engineer, desires position as assistant, resident or designing engineer. College graduate, eight years electrical manufacturing companies; five years constructing and operating. Particularly qualified as designing or assistant electrical engineer-power stations, transmission, industrial control, electrical rolling mills, specifications and technical correspondence. English, 6'-0", 150 pounds; total abstainer; married.

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602. Electrical Engineer, technical graduate, (1915) age 25; desires permanent position with central station or railway company, or in research or design work with manufacturing company; some experience in each. At present employed.

603. Electro-Mechanical Engineer, technical graduate and post; age 27; desires to make connection with engineering school in electrical design of machines or professor of electrical-mechanical subjects. Two years' experience in industrial education, and practical design in engineering college. Practical operation and repair of gas, steam, gasoline and oil engines, as well as hydraulic work.

604. Graduate Mechanical and Electrical Engineer. Professor of mechanical engineering four years in Eastern state college. Three and one-half years' experience in a-c. and d-c. electrical railway operation and design, designing and developing air compressors and motors, as well as executive experience as Secretary, Treasurer and General Manager of small corporation. Age 29; married.

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OFFICERS AND BOARD OF DIRECTORS, 1916-1917.

PRESIDENT.

(Term expires July 31, 1917)

H. W. BUCK

JUNIOR PAST-PRESIDENTS.

(Term expires July 31, 1917)
PAUL M. LINCOLN

(Term expires July 31, 1918)
JOHN J. CARTY

VICE-PRESIDENTS.

(Term expires July 31, 1917)
C. A. ADAMS
J. FRANKLIN STEVENS
WILLIAM McCLELLAN

(Term expires July 31, 1918)
B. A. BEHREND
P. JUNKERSPELD
L. T. ROBINSON

MANAGERS.

(Term expires July 31, 1917)
FREDERICK BEDELL
BANCROFT GHERARDI
A. S. McALLISTER
JOHN H. FINNEY

(Term expires July 31, 1918)
F. B. JEWETT
JOHN B. TAYLOR
HAROLD PENDER

(Term expires July 31, 1919)
C. E. SKINNER
JOHN B. FISKEN
N. A. CARLE

(Term expires July 31, 1920)
CHARLES S. RUFFNER
CHARLES ROBBINS

TREASURER (Term expires July 31, 1917) **SECRETARY.**

GEORGE A. HAMILTON — F. L. HUTCHINSON

HONORARY SECRETARY.
RALPH W. POPE

LIBRARIAN.
W. P. CUTTER

GENERAL COUNSEL.
PARKER and AARON,
52 Broadway, New York.

PAST PRESIDENTS.—1884-1916.

*NORVIN GREEN, 1884-5-6.
*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMPSON, 1889-90
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-92
FRANK JULIAN SPRAGUE, 1892-3.
*EDWIN J. HOUSTON, 1893-4-5.
*LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
A. E. KENNELLY, 1898-1900.
CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-02
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4
JOHN W. LIEB, 1904-5
SCHUYLER SKAATS WHEELER, 1905-6
SAMUEL SHELDON, 1906-7.
HENRY G. STOTT, 1907-8
LOUIS A. FERGUSON, 1908-09.
LEWIS B. STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.
RALPH D. MERSHON, 1912-13.
C. O. MAILLOUX, 1913-14.
PAUL M. LINCOLN, 1914-15.
JOHN J. CARTY, 1915-16.

*Deceased.

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INSTITUTE COMMITTEES.

Revised to November 1, 1916.

GENERAL STANDING COMMITTEES.

EXECUTIVE COMMITTEE.

H. W. Buck, Chairman,
49 Wall Street, New York.
N. A. Carle, George A. Hamilton,
John H. Finney, William McClellan,
Bancroft Gherardi, J. Franklin Stevens.

FINANCE COMMITTEE.

J. Franklin Stevens, Chairman,
1326 Chestnut Street, Philadelphia, Pa.
N. A. Carle, Bancroft Gherardi.

MEETINGS AND PAPERS COMMITTEE.

L. T. Robinson, Chairman,
General Electric Company, Schenectady, N.Y.
L. W. Chubb, Secretary, W. E. and M. Co. East Pittsburgh, Pa.
Frederick Bedell, F. W. Peek, Jr.
Philander Betts, F. L. Rhodes,
J. G. De Remer, D. W. Roper,
H. A. Hornor, Harris J. Ryan,
Edward P. Hyde, T. H. Schoepf
L. E. Imlay, Charles P. Steinmetz,
E. H. Martindale, N. W. Storer,
Wilfred Sykes.

EDITING COMMITTEE.

W. I. Slichter, Chairman,
Columbia University, New York.
Frederick Bedell, L. T. Robinson,
M. G. Lloyd, C. E. Skinner.

CODE COMMITTEE.

Farley Osgood, Chairman,
763 Broad Street, Newark, N. J.
J. C. Forsyth, H. R. Sargent,
H. B. Gear, G. A. Sawin,
A. H. Griswold, A. M. Schoen,
H. O. Lacount, George F. Sever,
Johnston Livingston, C. E. Skinner,
Henry N. Muller H. S. Warren.

BOARD OF EXAMINERS.

A. S. McAllister, Chairman,
Engineers' Club, 32 West 40th Street, New York.
E. B. Katte, W. I. Slichter,
F. L. Rhodes, Philip Torchio.

SECTIONS COMMITTEE.

W. A. Hall, Chairman,
General Electric Company, West Lynn, Mass.
J. G. De Remer, A. M. Schoen,
Paul M. Lincoln, J. H. Tracy,
and the chairmen of all Institute Sections, *ex-officio*.

MEMBERSHIP COMMITTEE.

Harold Goodwin, Jr., Chairman,
1000 Chestnut Street, Philadelphia, Pa.
G. M. Baker W. G. Chace,
S. H. Blake, H. W. Flashman,
E. H. Martindale.
and the chairmen of the Membership Committees of all Sections.

PUBLIC POLICY COMMITTEE.

Calvert Townley, Chairman,
165 Broadway, New York.
E. A. Carolan, William McClellan,
John J. Carty, H. H. Porter,
Fredk. Darlington, C. S. Ruffner,
Gano Dunn, A. M. Schoen,
John B. Fisken, L. B. Stillwell,
A. M. Hunt, H. G. Stott.

COMMITTEE ON DEVELOPMENT OF WATER POWER.

John H. Finney, Chairman,
509 Metropolitan Bank Building, Washington, D. C.
F. O. Blackwell, E. A. Lof,
Francis Blossom, W. V. N. Powelson,
Gano Dunn, L. B. Stillwell,
Nicholas S. Hill, Jr., H. G. Stott.

STANDARDS COMMITTEE.

C. A. Adams, Chairman,
Harvard University, Cambridge, Mass.
Harold Pender, Secretary,
University of Pennsylvania, Philadelphia, Pa.
P. G. Agnew, P. Junkersfeld,
Frederick Bedell, A. E. Kennelly,
L. F. Blume, G. L. Knight,
James Burke, A. S. McAllister,
G. A. Burnham, W. M. McConahey,
N. A. Carle, W. L. Merrill,
E. J. Cheney, Charles Robbins,
E. H. Colpitts, L. T. Robinson,
F. P. Cox, C. H. Sharp,
W. A. Del Mar, C. E. Skinner,
E. J. Edwards, A. J. Slade,
H. W. Fisher, N. W. Storer,
H. M. Hobart, H. G. Stott,
H. D. James, R. B. Williamson.

UNITED STATES NATIONAL COMMITTEE OF THE INTERNATIONAL ELECTRO-TECHNICAL COMMISSION.

C. O. Mailloux, President,
20 Nassau Street, New York.
F. B. Crocker, Vice-President,
A. E. Kennelly, Secretary,
Harvard University, Cambridge, Mass.
C. A. Adams, E. B. Rosa,
B. A. Behrend, Charles F. Scott,
Louis Bell, Clayton H. Sharp,
James Burke, Samuel Sheldon,
John J. Carty, C. E. Skinner,
Gano Dunn, Charles P. Steinmetz,
H. M. Hobart, H. G. Stott,
John W. Lieb, Elihu Thomson,
R. B. Owens, Philip Torchio.
M. I. Pupin,

PATENT COMMITTEE.

Ralph D. Mershon, Chairman,
80 Maiden Lane, New York.
Bion J. Arnold, Charles A. Terry,
John F. Kelly, B. F. Wood.

EDISON MEDAL COMMITTEE.

Appointed by the President for terms of five years.

Term expires July 31, 1917.

A. E. Kennelly, Chairman, Robert T. Lozier,
S. G. McMeen.

Term expires July 31, 1918.

H. W. Buck, F. A. Scheffler,
J. Franklin Stevens.

Term expires July 31, 1919.

Charles F. Brush N. W. Storer
C. C. Chesney,

Term expires July 31, 1920.

Carl Hering Harris J. Ryan
H. G. Stott.

Term expires July 31, 1921.

W. C. L. Eglin, Bancroft Gherardi,
E. W. Rice, Jr.

Elected by the Board of Directors from its own membership for terms of two years.

Term expires July 31, 1917.

B. A. Behrend, Paul M. Lincoln,
William McClellan.

Term expires July 31, 1918.

C. A. Adams, Harold Pender,
C. E. Skinner.

Ex-Officio.

H. W. Buck, President,
George A. Hamilton, Treasurer,
P. L. Hutchinson, Secretary.

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TECHNICAL COMMITTEES.

Revised to November 1, 1916.

POWER STATIONS.

J. G. De Remer, Chairman,
100 Broadway, New York.

J. M. Drabelle,
C. C. Egbert,
W. S. Gorsuch,
John Harisberger,
A. H. Kruesi,
Paul M. Lincoln,
Wynn Meredith,
I. E. Moultrop,
S. A. Moss,
R. J. S. Pigott,
Cecil Poole,
E. F. Scattergood,
F. A. Scheffler,
H. G. Stott,
W. R. Thompson,
Philip Torchio,
H. L. Wallau,
B. F. Wood.

TRANSMISSION AND DISTRIBUTION.

L. E. Imlay, Chairman,
Niagara Falls Power Co., Niagara Falls, N. Y.

H. A. Barre,
M. T. Crawford,
E. E. F. Creighton,
H. H. Dewey,
P. M. Downing,
H. W. Fisher,
F. A. Gaby,
W. T. Goddard,
O. A. Havill,
R. P. Hayward,
J. P. Jollyman,
P. M. Lincoln,
W. E. Mitchell,
G. J. Newton,
L. C. Nicholson,
W. D. Peaslee,
Stefaan Piek,
C. S. Ruffner,
H. J. Ryan,
F. D. Sampson,
H. E. Shedd,
Julian C. Smith,
P. H. Thomas.

TRACTION AND TRANSPORTATION.

N. W. Storer, Chairman,
Westinghouse E. & M. Co., East Pittsburgh, Pa.

Harry H. Adams,
A. H. Babcock,
Reinier Beeuwkes,
E. J. Blair,
L. P. Crecelius,
J. V. B. Duer,
George Gibbs,
W. J. Harvie,
Hugh Hazelton,
E. B. Katte,
P. J. Kearny,
William McClellan,
John Murphy,
W. B. Potter,
E. D. Priest,
Charles H. Quinn,
Clarence Renshaw,
A. S. Richey,
Charles F. Scott,
John B. Taylor,
H. S. Warren.

INDUSTRIAL AND DOMESTIC POWER.

E. H. Martindale, Chairman,
National Carbon Co., Cleveland, Ohio.

J. H. Davis,
A. M. Dudley,
Herbert B. Dwight,
F. W. Ells,
J. E. Fries,
F. R. Fishback,
R. H. Goodwillie,
A. L. Hadley,
G. A. Johnstone,
C. A. Kelsey,
C. L. Kennedy,
Charles D. Knight,
A. H. Lawton,
A. M. MacCutcheon,
A. G. Pierce,
James M. Smith,
H. Weichsel,
J. B. Wiard,
R. B. Williamson.

LIGHTING AND ILLUMINATION.

Edward P. Hyde, Chairman,
Nela Park, Cleveland, O.

G. M. Chamberlin,
C. E. Clewell,
J. R. Cravath,
T. S. Perkins,
Richard C. Powell,
E. B. Rosa,
W. D'A. Ryan,
Clayton H. Sharp,
W. M. Skiff.

ECONOMICS OF ELECTRIC SERVICE.

Philander Betts, Chairman,
790 Broad Street, Newark, N. J.

Harold Almert,
W. H. Blood, Jr.,
Fred A. Bryan,
C. L. Cory,
Harry Clifford Eddy,
W. B. Jackson,
A. H. Kruesi,
William McClellan,
Norman C. McPherson,
Allard Smith,
H. G. Stott,
W. G. Vincent,
George W. Whittemore,
G. W. Wilder

PROTECTIVE DEVICES.

D. W. Roper, Chairman
Room 500, 72 W. Adams St., Chicago, Ill.

L. L. Elden,
G. Faccioli,
V. E. Goodwin,
E. M. Hewlett,
Paul M. Lincoln
A. A. Meyer,
L. C. Nicholson,
N. L. Pollard,
S. D. Sprong,
Philip Torchio,
H. R. Woodrow.

ELECTROCHEMISTRY AND ELECTRO-METALLURGY.

T. H. Schoepf, Chairman,
W. E. and M. Co., East Pittsburgh, Pa.

Wesley J. Beck,
F. A. J. Fitzgerald,
A. F. Ganz,
F. A. Lidbury,
F. G. Liljenroth,
Eugene F. Roeber,
J. A. Seede,
R. Tschentscher,
Frank S. Washburn

ELECTROPHYSICS.

F. W. Peek, Jr., Chairman,
General Electric Company, Pittsfield, Mass.

Frederick Bedell,
A. C. Crehore,
G. Faccioli,
C. L. Fortescue,
W. S. Franklin,
A. E. Kennelly,
E. B. Rosa,
Harris J. Ryan,
Clayton H. Sharp,
C. P. Steinmetz,
P. H. Thomas,
J. B. Whitehead.

TELEGRAPHY AND TELEPHONY.

P. L. Rhodes, Chairman,
15 Dey St., New York.

E. F. W. Alexanderson,
R. E. Chetwood,
M. M. Davis,
C. L. Fortescue,
H. M. Friendly,
F. B. Jewett,
S. M. Kintner,
Wm. Maver, Jr.,
Kempster B. Miller,
H. Mouradian,
W. O. Pennell,
Allard Smith,
John S. Stone,
John B. Taylor,
J. L. Wayne, 3rd,
G. M. Yorke.

MARINE.

H. A. Hornor, Chairman,
Hamilton Court, 39th & Chestnut Sts., Philadelphia, Pa.

D. M. Mahood, Secretary,
Sperry Gyroscope Company,
Manhattan Bridge Plaza, Brooklyn, N. Y.

R. B. Chillas, Jr.,
M. W. Day,
G. E. Edgar,
W. L. R. Emmet,
W. R. Furlong,
H. L. Hibbard,
Guy Hill,
O. P. Loomis,
G. A. Pierce, Jr.,
H. M. Southgate,
E. A. Sperry,
Wilfred Sykes,
F. W. Wood.

COMMITTEE ON USE OF ELECTRICITY IN MINES

H. H. Clark, Chairman,
U. S. Bureau of Mines,
40th & Butler Streets, Pittsburgh, Pa.

Frank E. Alexander,
Frank H. Armstrong,
Graham Bright,
W. A. Chandler,
F. J. Duffy,
L. C. Ilsley,
R. L. Kingsland,
Charles Legrand,
Charles M. Means,
K. A. Pauly,
H. M. Warren.

IRON AND STEEL INDUSTRY.

Wilfred Sykes, Chairman,
Box 242, East Liberty, Pa.

S. C. Coey,
F. B. Crosby,
E. Friedlaender,
E. S. Jefferies,
D. M. Petty,
A. G. Pierce,
J. C. Reed,
R. Tschentscher,
Brent Wiley,
R. B. Williamson,
J. H. Wilson.

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SPECIAL COMMITTEES.

Revised to November 1, 1916.

REORGANIZATION OF TECHNICAL COMMITTEES.

L. T. Robinson, Chairman,
General Electric Company, Schenectady, N. Y.
F. L. Hutchinson, H. H. Norris,
A. S. McAllister, J. Franklin Stevens,
N. W. Storer.

PROPOSED RESERVE CORPS OF ENGINEERS.

Bion J. Arnold, Chairman,
105 South La Salle Street, Chicago, Ill.
John Harisberger, A. M. Schoen,
Ralph D. Mershon, Charles W. Stone.

COMMITTEE ON CODE OF PRINCIPLES OF PROFESSIONAL CONDUCT.

George F. Sever, Chairman,
13 Park Row, New York.
A. H. Babcock, John F. Kelly,
Gano Dunn, A. S. McAllister,
Schuyler Skaats Wheeler.

INSTITUTE REPRESENTATIVES.

ON BOARD OF AWARD, JOHN FRITZ MEDAL.

Ralph D. Mershon, Paul M. Lincoln,
C. O. Mailloux, John J. Carty,

ON BOARD OF TRUSTEES, UNITED ENGINEERING SOCIETY.

H. H. Barnes, Jr., Gano Dunn,
Samuel Sheldon.

ON LIBRARY BOARD OF UNITED ENGINEERING SOCIETY.

Samuel Sheldon, W. I. Slichter,
Harold Pender, Edward D. Adams,
F. L. Hutchinson.

ON ELECTRICAL COMMITTEE OF NATIONAL FIRE PROTECTION ASSOCIATION.

The chairman of the Institute's Code Committee.

ON ADVISORY BOARD OF AMERICAN YEAR-BOOK.

Edward Caldwell.

ON COUNCIL OF AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.

W. S. Franklin, G. W. Pierce.

ON CONFERENCE COMMITTEE OF NATIONAL ENGINEERING SOCIETIES.

Calvert Townley, William McClellan,
John J. Carty.

ON JOINT COMMITTEE ON ENGINEERING EDUCATION.

Charles F. Scott, Samuel Sheldon.

ON NATIONAL JOINT COMMITTEE ON OVERHEAD AND UNDERGROUND LINE CONSTRUCTION.

Farley Osgood, F. B. H. Paine,
Percy H. Thomas.

ON JOINT NATIONAL COMMITTEE ON ELECTROLYSIS.

Bion J. Arnold, F. N. Waterman,
Paul Winsor.

ON U. S. NATIONAL COMMITTEE OF THE INTERNATIONAL ILLUMINATION COMMISSION.

A. E. Kennelly, C. O. Mailloux,
Clayton H. Sharp.

ON JOINT COMMITTEE ON CLASSIFICATION OF TECHNICAL LITERATURE.

F. B. Jewett.

ON ENGINEERING FOUNDATION BOARD.

Michael I. Pupin.

ON NAVAL CONSULTING BOARD.

Benjamin G. Lamme, Frank J. Sprague.

ON PAN-AMERICAN ENGINEERING COMMITTEE.

Gano Dunn, William McClellan,
John H. Finney, Charles W. Stone.
Calvert Townley.

ON JOINT COMMITTEE ON METRIC SYSTEMS.

A. E. Kennelly, H. G. Stott.

ON AMERICAN ENGINEERING STANDARDS

C. A. Adams, N. A. Carle,
P. Junkersfeld.

LOCAL HONORARY SECRETARIES.

Guido Semenza, N. 10 Via S. Radegonda, Milan, Italy.
Robert Julian Scott, Christchurch, New Zealand.
T. P. Strickland, N. S. W. Government Railways, Sydney, N. S. W.
W. G. T. Goodman, Adelaide, South Australia.
James S. Fitzmaurice, Perth, West Australia.
L. A. Herdt, McGill Univ., Montreal, Que.
Henry Graftio, Petrograd, Russia.
Richard O. Heinrich, Genest-str. 5, Schoeneberg, Berlin, Germany.
A. S. Garfield, 45 Boulevard Beausejour Paris, 16 E., France
Harry Parker Gibbs, Tata Hydroelectric Power Supply Co., Ltd., Bombay, India.
John W. Kirkland, Johannesburg, South Africa.

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LIST OF SECTIONS

Revised to November 1, 1916.

Name and when Organized	Chairman	Secretary
Atlanta.....Jan. 19, '04	A. M. Schoen	H.E.Bussey,3d Nat. Bk. Bldg. Atlanta,Ga.
Baltimore.....Dec. 16, '04	J. B. Whitehead	L.M.Potts,Industrial Bldg.,Baltimore,Md.
Boston.....Feb. 13, '03	Geo. A. Burnham	Ira M.Cushing,84 State St.,Boston,Mass.
Chicago.....1893	Taliaferro Milton	W. J. Crumpton, 111 W. Monroe St. Chicago, Ill.
Cleveland.....Sept. 27, '07	E. W. P. Smith	Bruce W. David, Lincoln Electric Co., Cleveland, Ohio.
Denver.....May 18, '15	H. S. Sands	Robert B. Bonney, Mountain States Tel. and Tel. Co., Denver, Colo.
Detroit-Ann Arbor.....Jan. 13, '11	A. A. Meyer	A. Oakes, American Electrical Heater Company, Detroit, Mich.
Fort Wayne.....Aug. 14, '08	J. J. Kline	
Indianapolis-Lafayette..Jan. 12, '12	J. L. Wayne, 3rd	Walter A. Black, 3042 Graceland Ave., Indianapolis, Ind.
Ithaca.....Oct. 15, '02	E. L. Nichols	W. G. Catlin, Cornell Univ., Ithaca, N. Y.
Kansas City, Mo......Apr. 14, '16	Gordon Weaver	Glenn O. Brown, Kansas City Elec. Lt. Co., Kansas City, Mo.
Los Angeles.....May 19, '08	R. H. Manahan	Carl E. Johnson, 459 East Third Street, Los Angeles, Cal.
Lynn.....Aug. 22, '11	Gordon Campbell	M. B. Carroll, Gen. Elec. Co., West Lynn, Mass.
Madison.....Jan. 8, '09	F. A. Kartak	L. E. A. Kelso, University of Wisconsin, Madison, Wis.
Mexico.....Dec. 13, '07		
Milwaukee.....Feb. 11, '10	F. W. Ells	H. P. Reed, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.....Apr. 7, '02		Vernon S. Beck, Beck Elec. Const. Co., Minneapolis, Minn.
Panama.....Oct. 10, '13	Earl J. Atkisson	C. W. Markham, Balboa Heights, C. Z.
Philadelphia.....Feb. 18, '03	H. P. Liversidge	W. F. James, 14th Floor, Widener Bldg., Philadelphia, Pa.
Pittsburgh.....Oct. 13, '02	G. C. Hecker	F. E. Wynne, W. E. and M. Company, East Pittsburgh, Pa.
Pittsfield.....Mar. 25, '04	V. E. Goodwin	E. K. Shelton, General Electric Company, Pittsfield, Mass.
Portland, Ore......May 18, '09	L. T. Merwin	J. C. Martin, Pacific Power and Light Co., Portland, Oregon.
Rochester.....Oct. 9, '14	O. W. Bodler	Lucien Buck, 1416 Lake Avenue, Rochester N. Y.
St. Louis.....Jan. 14, '03	W. O. Pennell	George McD. Johns, Room 401, City Hall, St. Louis, Mo.
San Francisco.....Dec. 23, '04	J. E. Woodbridge	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
Schenectady.....Jan. 26, '03	C. E. Eveleth	H. L. Andrews, General Electric Company, Schenectady, N. Y.
Seattle.....Jan. 19, '04	C. E. Magnusson	C. F. Terrell, Puget Sound Trac. Lt. and Power Co., Seattle, Wash.
Spokane.....Feb. 14, '13	D. F. Henderson	C. M. Fisher, Washington Water Power Company, Spokane, Wash.
Toledo.....June 3, '07	W. E. Richards	Max Neuber, Cohen, Freidlander & Martin, Toledo, Ohio.
Toronto.....Sept. 30, '03	E. T. J. Brandon	Wills Maclachlan, 910 Excelsior Life Building, Toronto, Ont.
Urbana.....Nov. 25, '02	I. W. Fisk.	L. V. James, Univ. of Illinois, Urbana, Ill.
Vancouver.....Aug. 22, '11	R. F. Hayward	T. H. Crosby, Canadian Westinghouse Co., Vancouver, B. C.
Washington, D.C......Apr. 9, '03	Arthur Dunlop	Louis G. Freeman, U. S. Geological Survey, Washington, D. C.

Total 33

LIST OF BRANCHES

Name and when Organized	Chairman	Secretary
Agricultural and Mech. College of Texas.....Nov. 12, '09	A. Dickie	G. B. Hanson.
Alabama, Univ. of.....Dec. 11, '14	Gustav Wittig	A. F. Frazier, University, Ala.
Arkansas, Univ. of.....Mar. 25, '04	A. L. Wilson	W. L. Teague, University of Arkansas, Fayetteville, Ark.
Armour Institute.....Feb. 26, '04	Ralph H. Earle	Harold A. Kleinman, 7743 Burnham Avenue, Chicago, Ill.
Brooklyn Poly. Inst......Jan. 14, '16	Albert H. Bernhard	Walter J. Seeley, The Polytechnic Institute, Brooklyn, N. Y.
Bucknell University....May 17, '10	N. J. Rehman	E. C. Hageman, Bucknell University, Lewisburg, Pa.
California, Univ. of.....Feb. 9, '12	Marc Holzer	A. C. Maynard, University of California, Berkeley, Cal.
Carnegie Inst. of Tech..May 18, '15	E. G. Peterson	B. C. Dennison, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of.....Apr. 10, '08	R. L. Utley	H. V. McCormick, 3110 Woodburn Ave., Cincinnati, Ohio.
Clarkson Col. of Tech...Dec. 10, '15	H. H. Plank	Philip R. Cloke, Clarkson College of Technology, Potsdam, N. Y.
Clemson Agricultural Col. Nov. 8, '12	D. H. Banks	W. H. Neil, Clemson College, S. C.
Colorado State Agricultural College.....Feb. 11, '10	H. W. McKinley	F. G. Stiers, Colorado State Agricultural College, Fort Collins, Colo.

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LIST OF BRANCHES—Continued.

Name and when Organized	Chairman	Secretary
Colorado, Univ. of.....Dec. 16, '04	Charles C. Clymer	Victor E. Leroy, University of Colorado, Boulder, Colo.
Georgia School of Technology.....June 25, '14	C. R. Brown	J. E. Thompson, Georgia School of Technology, Atlanta, Ga.
Highland Park College..Oct. 11, '12	E. E. Gould	Adolph Shane, Highland Park College, Des Moines, Iowa.
Idaho, Univ. of.....June 25, '14	E. R. Hawkins	C. L. Rea, Univ. of Idaho, Moscow, Idaho.
Iowa State College.....Apr. 15, '03	C. L. Merrick	F. A. Robbins, Iowa St. Col., Ames, Iowa.
Iowa, Univ. of.....May 18, '09	H. W. Matson	A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col...Jan. 10, '08	Walter E. Deal	G. B. McNair, Kansas State Agri. Col., Manhattan, Kansas.
Kansas, Univ. of.....Mar. 18, '08	N. M. Foster	G. M. Bowman, 1517 New Hampshire, Lawrence, Kansas.
Kentucky, State Univ. of Oct. 14, '10	H. E. Melton	Margaret Ingels, 251 Delmar Avenue, Lexington, Ky.
Lafayette College.....Apr. 5, '12	Samuel McC. Hunt	Carl Theodore Mack, 418 McCartney Street, Easton, Pa.
Lehigh University.....Oct. 15, '02	F. L. Magee	J. F. Wentz, Lehigh University, South Bethlehem, Pa.
Lewis Institute.....Nov. 8, '07	P. B. Woodworth	
Maine, Univ. of.....Dec. 26, '06	Fred P. Jones	G. K. Wadlin, Lambda Chi Alpha House, Orono, Maine.
Michigan, Univ. of.....Mar. 25, '04	A. N. Clarke	F. E. Richardson, University of Michigan, Ann Arbor, Mich.
Minnesota, Univ. of....May 16, '16	Jesse L. Thompson	Donald P. Loye, 4216 Dupont Ave., South Minneapolis, Minn.
Missouri Univ. of.....Jan. 10, '03	K. Atkinson	A. C. Lanier, University of Missouri, Columbia, Mo.
Montana State Col.....May 21, '07	Carl Ladenburg	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of.....Apr. 10, '08	Olin J. Ferguson	V. L. Hollister, Station A., Lincoln, Nebr.
North Carolina Col. of Agr., and Mech. Arts.....Feb. 11, '10	F. E. Coxe	R. M. Hooper, N. C. Coll. of A. and M. Arts, West Raleigh, N. C.
North Carolina, Univ. of.Oct. 9, '14	Edw. Y. Keesler	W. H. Joyner, Univ. of North Carolina, Chapel Hill, N. C.
Norwich University.....June 28, '16		
Ohio Northern Univ.....Feb. 9, '12	W. C. Bedell	W. W. Wickerham, 125 S. Gilbert Street, Ada, Ohio.
Ohio State University....Dec. 20, '02	H. D. Bender	L. W. Birch, 138 Wheatland Avenue, Columbus, Ohio.
Oklahoma Agricultural and Mech. Col.....Oct. 13, '11	G. E. Davis	W. C. Lane, Oklahoma A. and M. College, Stillwater, Okla.
Oklahoma, Univ. of.....Oct. 11, '12	H. M. Richards	R. E. Heffner, University of Oklahoma, Norman, Okla.
Oregon Agr. Col.....Mar. 24, '08	J. A. Hooper	L. Happold, Oregon Agri. College, Corvallis, Ore.
Penn. State College....Dec. 20, '02	G. Geracimós	August Heine, State College, Pa.
Pittsburgh, Univ. of....Feb. 26, '14	E. R. Roth	W. B. Forman, University of Pittsburgh, Pittsburgh, Pa.
Purdue University.....Jan. 26, '03	C. F. Harding	A. N. Topping, Purdue Univ., Lafayette, Indiana.
Rensselaer Poly. Inst...Nov. 12, '09	W. J. Williams	W. R. Townsend, Jr., Rensselaer Polytechnic Institute, Troy, N. Y.
Rose Polytechnic Inst...Nov. 10, '11	H. E. Smock	Sam P. Stone, 1012 North 8th Street, Terre Haute, Ind.
Rhode Island State Col.Mar. 14, '13	C. E. Seifert	Frank A. Faron, Rhode Island State College, Kingston, R. I.
Stanford Univ.....Dec. 13, '07	H. W. Lewis	A. L. Morgan, Stanford University, Cal.
Syracuse Univ.....Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.....Feb. 14, '08	J. M. Bryant	J. A. Correll, Univ. of Texas, Austin, Tex.
Throop College of Technology.....Oct. 14, '10	J. W. DuMond	K.W. Rich, Throop College of Technology, Pasadena, Cal.
Virginia Polytechnic Institute.....Jan. 8, '15	John D. Hindle	E. S. Smithson, Virginia Polytechnic Institute, Blacksburg, Va.
Virginia, Univ. of.....Feb. 9, '12	W. S. Rodman	J.H. Peebles, University, Va.
Wash, State Col. of.....Dec. 13, '07	C. H. Worthen	C. J. Melrose, State Col. of Wash., Pullman, Wash.
Washington Univ.....Feb. 6, '04	Charles A. Lieber	R. W. Macdonald, Washington University, St. Louis, Mo.
Washington, Univ. of...Dec. 13, '12	A. Kalin	J. R. Himmelsbach, 4629 21st Avenue, Seattle, Wash.
West Virginia Univ.....Nov. 13, '14	O. P. Joliffe	D. F. Cronin, 52 University Driveway, Morgantown, W. Va.
Worcester Poly. Inst....Mar. 25, '04	C. W. Kennedy	J. A. Blair, Worcester Polytechnic Institute Worcester, Mass.
Yale University.....Oct. 13, '11	A. W. Cahoon	J. P. Allen, Sheffield Scientific School, New Haven, Conn.

Total 56.

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American Institute of Electrical Engineers

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PROCEEDINGS

Vol. XXXV **DECEMBER, 1916** **Number 12**

INSTITUTE MEETING IN BOSTON DECEMBER 8, 1916

The 327th meeting of the American Institute of Electrical Engineers will be held in Boston, Mass., Friday, December 8, 1916, under the auspices of the Boston Section and the Protective Devices Committee of the Institute. The Committee meetings in the morning and the technical session in the afternoon will be held at the Massachusetts Institute of Technology, Cambridge.

Committee Meetings

The Standards Committee will meet at 9:00 a.m. in Room 10-385, the Finance Committee at 10:30 a.m. in Room 4-209, and the Board of Directors at 11:00 a.m. in Room 10-200. The Board of Directors will take luncheon at the Harvard Club, Boston, at 1:00 p.m.

Inspection Trips

During the period from 9:00 a.m. to 1:00 p.m., members and guests of the Institute are invited to visit the South Boston Power Station of the Boston Elevated Railway Company, the L Street (South Boston) Power Station of the Edison Electric Illuminating Company, and the manufacturing plants of the Condit Electrical Manufacturing Company, makers of protective devices, at L and First Streets, South Boston, and of Gray and Davis, Inc., makers of electrical accessories for automobiles, at Cambridge. Presentation of a copy of the printed program of the Boston meeting will be sufficient to insure admission to all of these plants during the hours named.

Technical Session

The technical session in the afternoon to be devoted to the general subject of "The Rating of Oil Circuit Breakers with Reference to their Rupturing Capacity," will be held in the Central Lecture Hall of the Massachusetts Institute of Technology, beginning at 2:30 p.m.

The first paper, entitled *Rupturing Capacity of Oil Circuit Breakers*, will be presented by Mr. Stephen Q. Hayes, to be followed by a paper on *Rating of Oil Circuit Breakers*, by Mr. E. M. Hewlett.

Informal Dinner

At 6:30 p.m., an informal table d'hote dinner will be served to members and guests attending the meeting, at the Riverbank Court, on Massachusetts Avenue, Cambridge, directly opposite the Massachusetts Institute of Technology buildings.

Tickets for the dinner, for which the charge will be $1.50 per person, should be purchased at the Registration Headquarters before the technical session.

Hotels

No hotel has been designated as headquarters, but the Somerset and the Puritan are the nearest hotels to the meeting place. Members are advised to make their hotel reservations in ample time in advance of the meeting.

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PRESENTATION OF THE JOHN FRITZ MEDAL

In the evening will occur the ceremony of presentation of the John Fritz Medal to Dr. Elihu Thomson, as announced below.

PRESENTATION OF THE JOHN FRITZ MEDAL TO DR. ELIHU THOMSON

The John Fritz Medal, given in recognition of notable scientific or industrial achievement, which was provided for by a fund subscribed in memory of the great engineering pioneer, John Fritz, was awarded in January, 1916, to Dr. Elihu Thomson, past-president of the American Institute of Electrical Engineers, "for achievements in electrical inventions, in electrical engineering, and in industrial development, and in scientific research."

The formal presentation of the medal to Dr. Elihu Thomson will take place Friday evening, December 8, 1916, at 8:30 o'clock, in the Central Lecture Hall of the Massachusetts Institute of Technology, Cambridge, Mass. The John Fritz Medal Board of Award cordially invites members of engineering societies and others interested, including ladies, to attend the presentation ceremonies.

Professor Albert Sauveur, chairman of the John Fritz Medal Board of Award, will preside. The first address on the program will be delivered by Dr. John J. Carty, chairman of the Presentation Committee of the Board of Award, who will be followed by Mr. E. W. Rice, Jr., president of the General Electric Company, and Dr. Richard C. Maclaurin, president of the Massachusetts Institute of Technology. The presentation of the medal will be made by Dr. Charles Warren Hunt, past-chairman of the Board of Award, and Dr. Elihu Thomson's response will conclude the program.

The award of the medal is made by a permanent board representing the four national engineering societies. The members of the 1916 board, with the societies they represent, are:

American Society of Civil Engineers—
Charles Warren Hunt, John A. Ockerson, Geogre F. Swain, and Charles D. Marx.

American Institute of Mining Engineers—
Albert Sauveur, E. Gybbon Spilsbury, Charles F. Rand, and Christopher R. Corning.

American Society of Mechanical Engineers—
John R. Freeman, Ambrose Swasey, John A. Brashear, and Frederick R. Hutton.

American Institute of Electrical Engineers—
Ralph D. Mershon, C. O. Mailloux, Paul M. Lincoln, and John J. Carty.

NOMINATIONS FOR INSTITUTE OFFICERS FOR 1917-18

As provided in Section 20 of the Institute by-laws, candidates may now be proposed for nomination for the offices to be filled at the next annual election in May, 1917, by the petition or by the separate endorsement in writing, of not less than fifty members. The petitions or separate endorsements must be in the hands of the Secretary not later than January 25, 1917. For the convenience of members, a form of petition has been prepared by the Secretary, and copies of it may be obtained upon application to Institute headquarters. Endorsements may, however, be made by letter if the form is not available.

The officers to be elected are: a President and Treasurer, for the term of one year each, three Vice-Presidents for the term of one year each, and four Managers, of whom the junior one shall serve for three years and the senior three for four years each.

For the information of members, the full text of Section 20 of the by-laws,

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governing the proposal of candidates for nomination, is printed below:

Sec. 20. In addition to the names of the incumbents of office, the Secretary shall publish on 'the form showing offices to be filled at the ensuing annual election in May,' provided for in Article VI of the Constitution, the names, as candidates for nomination, of such members of the Institute as have been proposed for nomination for a particular office by the petition or by the separate endorsement of not less than fifty members, received by the Secretary of the Institute in writing by January 25 of each year.

FUTURE INSTITUTE MEETINGS.

The places and dates for Institute meetings in 1917, so far as authorized by the Board of Directors, are as follows:

Pittsburgh, Pa., January 12, 1917. Paper to be presented by Mr. R. E. Hellmund, *Regenerative Braking of Electric Vehicles.*

New York, February 7, 8, 9, 1917. Midwinter Convention.

Schenectady, N. Y., March 9, 1917.

Chicago, Ill., April 13, 1917.

New York, May 18, 1917. Annual Meeting.

The Annual Convention will be held during the week beginning June 25,1917.

The Pacific Coast Convention of 1917 will be held in Los Angeles, Cal., at a date to be announced later.

THIRTY-SEVENTH ANNUAL MEETING OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

The American Society of Mechanical Engineers will hold its thirty-seventh Annual Meeting in New York, December 5-8, 1916, in the Engineering Societies Building. A varied program has been arranged, with ten technical sessions, seven being devoted to the subjects of industrial safety, textile industry, machine shop practice, valuation, gas power, railroads, and steam boilders, and three to miscellaneous subjects.

The meeting will begin on Tuesday evening, December 5, when Dr. D. S. Jacobus, president of the society, will deliver the presidential address on "The Relation of Education to Engineering." After the introduction of the president-elect, there will be an informal reception to the president, president elect, ladies, members and guests.

At the opening session on Wednesday morning there will be held, following the business meeting, memorial exercises in honor of the memory of John E. Sweet, past-president and founder of the society.

A smoker has been arranged for Wednesday evening. Entertainment will be provided, and a feature of the evening will be a short talk by Mr. Frank B. Gilbreth on his experiences in Europe during the war.

On Thursday evening a lecture of a popular nature will be given in the auditorium, and the members and guests are invited to adjourn, after the lecture to the fifth floor of the Engineering Societies Building, for the annual reunion and dance.

The industrial safety session on Wednesday morning will be devoted to the consideration of a sub-committee report on "Safety Standards for the Operation of Cranes." On Friday afternoon, and continued on Saturday morning, there will be a public hearing conducted by the Boiler Code Committee.

ANNUAL MEETING OF SOCIETY OF AUTOMOBILE ENGINEERS

The Society of Automobile Engineers is planning to hold its Annual Meeting on January 11, 1917. A professional session, to which the members of the Institute are cordially invited, will be held on the afternoon of that day in the auditorium of the Engineering Societies Building. A comparatively small number of papers will be presented, and the various authors will read digests of their papers, thus allowing plenty of time for discussion.

The range of papers is such that almost every engineer will find something of interest. Of course, considerable attention will be paid to the

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automobile subjects, and papers are already in course of preparation dealing with high-speed engines, dynamics of the automobile, and electrical equipment. It is also expected that important papers will be presented on aerial navigation over water, and the use of motor boats in war. Captain V. E. Clark of the Signal Corps is to give a paper on the requirements of airplane design, particularly as regards the experience of the Army in using airplanes in Mexico.

CONVENTION OF AMERICAN INSTITUTE OF ARCHITECTS

The fiftieth annual convention of the American Institute of Architects will be held in Minneapolis, Minnesota, December 6-8, 1916. This convention, perhaps more than any previous one, will be devoted to the consideration of topics of broad public interest. A special session will be given up to a constructive discussion of Government methods in public building work, and another to architectural education in our universities.

The architects of the country, as members of the profession and regardless of affiliation with the American Institute of Architects, are invited to attend the convention and take part in its proceedings.

PLANS FOR THE GREATEST ENGINEERING LIBRARY

Dr. James Douglas of New York has presented $100,000 to the United Engineering Society, the income to be used for the benefit of the Library of the Engineering Societies.

The Trustees of the United Engineering Society have perfected plans for the development and the extension of the usefulness of this great engineering library and are endeavoring to secure endowments aggregating $1,000,000, the income to be used for the library.

The plans of the trustees, having been submitted to and carefully examined by Dr. Douglas, have been approved by him and he has signified this approval by his gift of $100,000 which has just been made.

Now that the Library of the American Society of Civil Engineers has been united with the libraries of the Institutes of Mining, Mechanical and Electrical Engineers in the building of the United Engineering Society in West 39th Street, New York, the combined library forms the greatest engineering collection in the world. It is the purpose of the trustees to extend greatly its usefulness and it is hoped that the splendid endorsement which Dr. Douglas has given will stimulate other similar endowments until the necessary million dollars have been obtained.

A. I. E. E. NEW YORK MEETING, NOVEMBER 10, 1916

The 326th meeting of the Institute was held in New York, in the auditorium of the Engineering Societies Building, on Friday, November 10, 1916, and was devoted to a topical discussion on the subject of "Inventories and Appraisals."

President H. W. Buck, in calling the meeting to order at 8:30 p.m., said that the question of inventories and appraisals has been the cause of more controversy and bitterness in engineering and financial circles than any other question in recent years, and that this has resulted largely from misunderstandings of the fundamentals governing the subject. It was for this reason that the Institute members were called together to discuss this important subject, in order to bring out the essential facts governing the principles involved. President Buck then introduced Dr. Philander Betts, chief engineer of the Public Utility Commission of New Jersey, who presented a paper on *The Effect of Recent Decisions on the Work of Inventory and Appraisal.*

Mr. Harry E. Carver, assistant engineer of the Public Utility Commission of New Jersey, then presented his

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paper entitled *Continuous Inventories; Their Preparation and Value*, and was followed by Mr. Julian Loebenstein, junior electrical engineer of the Public Service Commission of New York, First District, whose paper was entitled *Growth and Depreciation.*

Those who participated in the ensuing discussion were Messrs. William B. Jackson, George W. Whittemore, David B. Rushmore, Edward J. Cheney, William S. Franklin, Philander Betts and Harry E. Carver.

DIRECTORS' MEETING, NEW YORK, NOVEMBER 10, 1916

The regular monthly meeting of the Board of Directors of the Institute was held at Institute headquarters, New York, on Friday, November 10, 1916, at 3:30 p.m.

There were present: President H. W. Buck, New York, Past-Presidents Paul M. Lincoln, Pittsburgh, John J. Carty, New York; Vice-Presidents C. A. Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., B. A. Behrend, Boston, Mass., L. T. Robinson, Schenectady, N. Y.; Managers Frederick Bedell, Ithaca, N. Y., A. S. McAllister, New York, John H. Finney, Washington, D. C., John B. Taylor, Schenectady, N. Y., Harold Pender, Philadelphia, Pa., N. A. Carle, Newark, N. J., C. E. Skinner and Charles Robbins, Pittsburgh, Pa.; Treasurer George A. Hamilton, Elizabeth, N. J.; Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $7,366.18 was ratified.

The President was authorized to appoint a special committee including the chairman of the Meetings and Papers Committee, to consider and report to the Board upon the location of the Annual Convention for 1917.

The report of the Board of Examiners of its meeting held on November 2 was read, and the actions taken at that meeting were approved.

Upon the recommendation of the Board of Examiners, 47 applicants were elected to the grade of Associate, two applicants were elected to the grade of Member and 184 students were ordered enrolled.

Upon the petition of Professor W. W. Hill, of the Alabama Polytechnic Institute, Auburn, Alabama, and with the approval of the chairman of the Sections Committee, the organization of a Branch was authorized at that institution.

Upon the recommendation of the Pacific Coast Convention Committee, which had charge of the arrangements for the Pacific Coast Convention held in Seattle in September, the Board authorized the 1917 Pacific Coast Convention to be held in Los Angeles, California, at a date to be selected by the Los Angeles Section.

The Board approved the suggestion of a joint meeting of the four national engineering societies with the Engineering Section of the American Association for the Advancement of Science, including a reception by the engineers to the members of the A. A. A. S., during the convention of the latter association in New York the last week in December, 1916. The Secretary was authorized to join with the officers of other engineering societies in extending an invitation to the A. A. A. S., and the President was authorized to appoint representatives upon any joint committee that may be necessary in connection with this proposed meeting and reception.

The Board voted to hold its next meeting in Boston, on Friday, December 8, 1916, at 11:00 a.m.

PAST SECTION MEETINGS

Baltimore.—October 20, 1916, John Hopkins University. Paper: "Corona Voltmeter," by J. B. Whitehead. After presentation of the paper Dr. Whitehead gave a demonstration of the operation of the instrument and other corona phenomena. Attendance 35.

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November 17, 1916, Johns Hopkins University. Paper: "The Influence of Dielectric Losses on the Rating of High-Tension Underground Cables," by A. Bang and H. C. Louis. Attendance 42.

Boston.—October 10, 1916, Engineers Club. Address by Prof. C. A. Adams on "Notes on Cables and Cable Testing." Attendance 100.

Cleveland.—October 16, 1916, Electrical League Rooms. Paper: "The Present-Day Aspect of the Electric Furnace," by W. McA. Johnson. Attendance 64.

Denver.—October 21, 1916, Denver Athletic Club. Illustrated lecture by Mr. H. W. Whitehead on "Electrolytic Refining and Separation of Precious Metals." Attendance 25.

Indianapolis-Lafayette.—October 20, 1916, Indianapolis. Addresses by Dr. D. S. Jacobus, President, Calvin W. Rice, Secretary, and Elliot H. Whitlock, Manager, of the A. S. M. E. Joint meeting with A. S. M. E.

Ithaca.—October 27, 1916, Franklin Hall, Cornell University. Papers: (1) "Some Problems of the Research Laboratory of a Large Public Service Corporation," by J. F. Putnam; (2) "Recent Advances in Radio Communication," by William C. Ballard. Attendance 71.

October 30, 1916. Election of Officers as follows— chairman, Frederick Bedell; secretary, William Deans; members of executive committee, Alexander Gray and V. Karapetoff.

Kansas City.—October 17, 1916, Y. M. C. A. Paper: "Oil Well Electrification," by W. F. Barnes. Prof. George C. Shaad gave a report on the Cleveland Convention. Attendence 16.

Lynn.—October 11, 1916, Lynn Classical High School. Illustrated address by Mr. Elmer A. Sperry on "The Gyroscope and Its Engineering Applications." Mr. Sperry gave a demonstration of the principle of the gyroscope by means of actual models. Attendance 400.

Milwaukee.—October 11, 1916, Gold Room, Hotel Wisconsin. Illustrated address by Prof. J. G. Callan on "Recent Tendencies in Gas Engine Design." Joint meeting with A. S. M. E. Attendance 140.

November 8, 1916, Republican House Illustrated address by Mr. John D. Ball on "Magnetic Properties of Iron and Steel." Attendance 60.

Pittsburgh.—October 21, 1916, Fort Pitt Hotel. Papers: (1) "Central Station Power for Steel Mills," committee report abstracted by Brent Wiley; (2) "The Advantages of Modern Types of Direct-Current Machines," by D. Hall. Joint meeting with A. I. & S. E. E. Attendance 115.

November 14, 1916, Western Penna. Engineering Society. Paper: "The Opportunity of the Engineering School" by C. R. Mann. Attendance 75.

Pittsfield.—October 10, 1916, Maplewood Hotel. Address by Dr. Charles P. Steinmetz on "Effect of the European War on American Industries." Attendance 235.

October 26, 1916, Wendell Hotel. Paper: "Insulating Oils," by Walter H. Miller. Attendance 160.

Rochester.—October 27, 1916, Engineering Society Rooms. Paper: "Merging the Falls of the Genesee," by F. J. Howes, F. W. Fisher and W. S. Burch. Attendance 39.

San Francisco.—October 27, 1916, Engineers Club. Paper: "Operation and Maintenance of Curtis Steam Turbine as Applied to Marine Craft," by W. J. Davis, Jr. Attendance 130.

Schenectady.—October 20, 1916, Edison Club Hall. Illustrated lecture by Mr. Frank J. Sprague on "A Month's Cruise with the Atlantic Fleet during the Winter Maneuvers, with a Review of the Part Taken by the Electrical Engineer in the Upbuilding of the Fleet." Attendance 340.

Spokane.—September 1, 1916, Spokane Hotel. Dinner to President H. W. Buck and Honorary Secretary Ralph W. Pope. Attendance 20.

October 20, 1916, Spokane Hotel. Paper: "Public Service Commissions," by F. S. Burroughs. Report on Cleve-

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land Convention by Mr. Chas. A. Lund. Attendance 46.

Toledo.—October 24, 1916, The Electric Converter Company. Address by Mr. Arthur Bullock on "A New Method of Rectifying Alternating Current into Direct Current." Attendance 75.

November 10, 1916, Toledo Commerce Club. Address by Prof. Benj. F. Bailey on "Application of Electricity to the Gasoline Automobile." Attendance 52.

Toronto.—October 20, 1916, Engineers Club. Address on "The Work of Accident Prevention," by Mr. Charles B. Scott, general manager of the Bureau of Safety, Chicago. Attendance 90.

PAST BRANCH MEETINGS

University of Arkansas.—October 16, 1916. Address on "Parsons Steam Turbine," by R. L. Belknap. Discussion of abstracts from technical press. Attendance 26.

November 6, 1916. Address on "The Arkansas Light and Power Company," by J. E. Douthit. Discussion of abstracts from technical press. Motion pictures on the manufacture of Mazda lamps. Attendance 26.

Armour Institute.—October 24, 1916. Papers: (1) "Operation and Cost of Maintenance of Large Storage Battery Plants," by James D. Harvey; (2) "Ignition Problems of High-Speed Multi-Cylinder Gas Engines," by Earl H. Smith. Attendance 35.

November 16, 1916. Papers: (1) "Voltage and Current Regulation on Automobile Starting and Lighting Systems," by L. H. Rosenberg; (2) "Electric Clocks," by H. A. Kleinman. Attendance 20.

Brooklyn Polytechnic Institute.—October 27, 1916, Mailloux Library. Address by Mr. Walter I. Tamlyn on the "Gyroscope Compass." Attendance 54.

University of California.—October 4, 1916. Paper: "The Entz Transmission in the Owen Magnetic Automobile," by A. C. Maynard. Attendance 17.

October 18, 1916. Paper: "The Economic Design of Railway Motors," by Mr. Lingle. Attendance 15.

University of Cincinnati.—October 24, 1916. Paper: "Motor Starters," by Oscar F. Shepard. Attendance 35.

November 14, 1916. Address by Mr. Frank Willey on "Limitations in Motor Design." Attendance 23.

Clarkson College of Technology.—October 5, 1916. Election of officers as follows—chairman, H. H. Plank; secretary, P. R. Cloke; treasurer, S. J. Wise. Address by Prof. A. R. Powers on "What is Expected of the College Graduate." Attendance 13.

October 18, 1916. Papers: (1) "Practical Illumination," by L. C. Tomlinson; (2) "Pneumatically Operated Devices on Locomotives and Cars," by W. J. Herrick. Attendance 15.

November 1, 1916. Paper: "Graphical Charts on Parallel Coordinates," by W. A. Dart. Attendance 19.

Colorado State Agricultural College.—October 13, 1916, Assembly Hall. Illustrated address by Mr. Whaland on "Electrification of the Large Eastern Railroads." Attendance 60.

Georgia School of Technology.—October 6, 1916, Electrical Building. Election of Officers as follows—chairman, R. E. Robinson; secretary-treasurer, John Farago. Address by Prof. H. P. Wood on "Advantages of Organization." Attendance 33.

October 13, 1916, Electrical Building. Paper: "The Location of Telephone Offices in an Exchange Area," by H. M. Keys. Attendance 33.

November 6, 1916, Electrical Building. Paper: "Fundamental Plans of Telephone Exchanges," by H. B. Wey. Attendance 33.

Highland Park College.—October 18, 1916. Electrical Engineering Building. Discussion on "Electrification of Railways." Attendance 29.

Iowa State College.—October 18, 1916. Address on "Apprentice Course for Technical Graduates Conducted by the Iowa Telephone Company," by Lewis Easner. Attendance 31.

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November 1, 1916. Discussion of Electrical Meters by Mr. W. W. Bruner. Attendance 30.

University of Kansas.—October 18, 1916, Marvin Hall. Address by Mr. Chas. W. Holliday on "Coal Mining in the Canadian Northwest." Messrs. Arlin and Fox told of experiences on the recent engineers' inspection trip. Attendance 40.

October 25, 1916, Marvin Hall. Illustrated address by Mr. L. M. Bocker on "Electrification of the Norfolk and Western Railway." Attendance 40.

November 9, 1916, Marvin Hall. Address by Mr. H. M. Biebel on "Experiences in Electrical Engineering." Attendance 44.

Lafayette College.—October 28, 1916, Papers: (1) "High-Frequency Tests of Line Insulators," by T. F. A. Lehmann; (2) "How Aluminum is Made," by L. H. Britton. Attendance 21.

November 11, 1916. Abstracts of the following papers were presented: "Line Shafting, Group and Individual Motor Drive," by S. M. Hunt; "The Choice of Drive between Motor and Machine," by M. R. Sarson. Attendance 20.

Lehigh University.—October 26,1916, Electrical Engineering Lecture Room. Papers: (1) "Thawing Pipes by Electricity," by E. C. Hummel; (2) "Systems of Car Lighting," by D. J. Cartwright. Attendance 82.

University of Maine.—November 8, 1916, Hannibal Hamlin Club Room. Address by Mr. Wadlin on "Summer Work with the American Telephone and Telegraph Company." Address by Mr. Hildergras on "Telephones and Progress." Attendance 48.

University of Michigan.—October 25, 1916. Paper: "What the Student's Branch of the American Institute of Electrical Engineers Means to Students of Electrical Engineering," by J. C. Parker. Attendance 81.

University of Missouri.—October 16, 1916, Engineering Building. Papers: (1) "The Institute, Its Purpose and Organization," by Professor Lanier; (2) "The Student Branch, Its Relation to the Institute and to the Students," by G. M. Duren; (3) "The Encouragement of Originality among Student Members," by G. A. Delaney. Attendance 12.

November 6, 1916, Engineering Building. Paper: "Recent Developments in Wireless Telephony." Attendance 17.

University of Minnesota.—October 16, 1916. Short talks by student members on summer work with the Minneapolis General Electric Company. Motion picture on the Panama Canal. Attendance 70.

Montana State College.—November 3, 1916, Electrical Building. Address by Mr. R. D. Sloan on "Construction and Operation of the Volta Station of the Montana Power Company." Attendance 37.

University of Nebraska.—November 8, 1916. Address by Mr. O. J. Fee on "Water Supply from the Commercial Standpoint." Attendance 23.

North Carolina College of Agricultural and Mechanical Arts.—October 17, 1916. Address by Mr. W. D. Marrow on "Experiences as an Electric Contractor and Consulting Engineer." Attendance 20.

October 25, 1916, Mr. B. B. Stockard gave an experiment with Faraday's disk. Attendance 18.

November 1, 1916. Messrs. F. E. Coxe, B. B. Brown and E. Maxwell gave demonstration of the X-ray in operation. Attendance 20.

November 8, 1916. Messrs. G. C. Cox, B. W. Boulamore and F. H. Prichard presented an experiment showing the effect of cathode rays on different solids, liquids and gases. Attendance 21.

Norwich University.—October 20, 1916. Address by Professor Lear on "The Aims of the A. I. E. E." Attendance 27.

Ohio Northern University.—October 18, 1916. Addresses as follows: (1) "Automobile Electrical Equipment," by Mr. Durnsburger; (2) "The Thury System," by Mr. Bayle.

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November 1, 1916. Papers: (1) "The Electron Theory of Magnetism," by Prof. Berger; (2) "Electric Furnaces," by W. E. Ward; (3) "Engineering Ethics," by Prof. McEachron.

Ohio State University.—November 3, 1916, Ohio Union. Addresses as follows—(1) "Power Sales," by Prof. Hitchcock; (2) "Electrical Conditions in Peru," by Mr. Kanmacher. Attendance 34.

University of Oklahoma.—October 18, 1916. Papers: (1) "Summer Engineering Work," by L. Holland; (2) "Oklahoma Railways," by R. Clark; (3) "Telephone Engineering," C. C. Oster; (4) "Personal Experiences," by Prof. Press. Attendance 34.

November 15, 1916. Papers: (1) "Research in Engineering Schools," by E. D. Freeman; (2) "Railway Electrification," by O. W. Walters; (3) "Engineering Education," by H. M. Richards. Attendance 20.

Oregon Agricultural College. — November 8, 1916. Paper: "External Characteristics of D-C. Generators," by S. H. Myers. Attendance 23.

Pennsylvania State College.—October 17, 1916, Engineering Club Room. Address by Mr. Bachman on "Summer Experience at the General Electric Plant at Erie, Pa." Attendance 38.

University of Pittsburgh.—October 17, 1916. Address on "The Origin and Object of the American Institute of Electrical Engineers." Election of officers as follows—chairman, E. R. Rath; vice-chairman, A. R. Rutter; Secretary-treasurer, W. B. Forman. Attendance 14.

Purdue University.—September 22, 1916, Electrical Building. Election of officers as follows—student chairman, R. H. Townsend; vice-chairman, H. S. Vaile; student secretary, E. F. Reasor; treasurer, S. S. Green. Attendance 40.

October 10, 1916, Electrical Building. Addresses as follows—(1) "Mining in Arizona," by F. K. Mitchell; (2) "The General Electric Company's Summer Student Course," by F. C. Rand; (3) "Army Service along the Border," by W. R. Miller. Attendance 61.

October 24, 1916, Electrical Building. Illustrated lecture by C. P. Cottingham. Motion pictures on the Panama Canal, Krupp Gun Works, Paper Making and Newspaper Printing, Process of Steel Making, Glacier National Park. Attendance 99.

October 27, 1916. Paper: "Some Phases of the Operation of the Mississippi River Power Company's Plant at Keokuk, Iowa," by R. B. Howland. Attendance 70.

Rensselaer Polytechnic Institute.—October 24, 1916, Sage Laboratory. Address by Dr. W. L. Robb on "The Purpose of the Rensselaer Branch of the Institute, and Its Various Activities." Attendance 72.

Rhode Island State College.—November 13, 1916, Science Hall. Paper: "Circuit Breakers, and Automatic Switches," by Mr. Thayer. Attendance 25.

Virginia Polytechnic Institute.—October 27, 1916, Lyric Theater. Lecture illustrated by motion pictures showing the construction and manufacture of a 35,000-kw. generator and other machines of interest. Attendance 205.

November 17, 1916, Science Hall. Address by Dr. J. E. Williams on "Mathematics for the Engineer." Attendance 45.

Washington University.—October 27, 1916, Cupples II. Paper: "Variations of Strength of Wireless Signals," by Mr. Blatterman. Attendance 34.

University of Washington.—October 24, 1916, Forestry Hall. Paper: "High Power Radio Plants in America," by F. M. Ryan. Attendance 31.

Washington State College.—September 29, 1916, Mechanics Arts Building. Address by Prof. O. L. Waller on "The Water Rights Law of the State of Washington." Attendance 23.

Worcester Polytechnic Institute.—October 20, 1916. The meeting was

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devoted to the discussion of summer experiences. Attendance 60.

Yale.—October 26th, 1916, 10 Hillhouse Avenue, New Haven. Illustrated address by Mr. W. C. L. Eglin on "The Power Company; Its Purpose and Equipment." Attendance 85.

PERSONAL

MR. WALTER C. ALLEN was recently appointed by the District Commissioners to the position of executive officer of the Public Utilities Commission of the District of Columbia. Mr. Allen has been in the service of the District about 22 years, having started with the street-lighting division as superintendent of lamps. In 1904 the position of electrical engineer was created and Mr. Allen became the District's first electrical engineer, which is the same as superintendent of the department. Under his administration a large number of Washington's streets have been provided with improved lighting systems.

MR. JAY GRANT DE REMER has opened an office for general consulting practise at 55 Liberty Street, New York, where he will carry on the engineering work formerly handled by the firm of Martin and De Remer, 100 Broadway. The latter firm was terminated November 1, 1916.

OBITUARY

ARTHUR CLARKE EASTWOOD, Fel. A. I. E. E., President of the Electric Controller and Manufacturing Company, of Cleveland, Ohio, died October 17, 1916 at Battle Creek, Michigan. Mr. Eastwood received his early education in the public schools of Louisville, Kentucky, and his technical education at the Rose Polytechnic Institute, from which he was graduated in 1898. Soon after he entered the electrical department of the Homestead Steel Works, and was associated with Mr. A. C. Dinkey in the first extensive applications of electrical power in the manufacture of steel. He left Homestead to accept the position of electrical engineer for the mills of the Tennessee Coal, Iron and Railway Company, then building at Ensley, Alabama. He was then asked to come to Cleveland to accept the positions of electrical engineer for the Wellman-Seaver Engineering Company and chief engineer for the newly formed Electric Controller and Supply Company. As a result of Mr. Eastwood's inventive ability, the growth of the latter company was so rapid that he was soon forced to give the business his entire attention, under the title of general manager and chief engineer. About 1905 Mr. Eastwood and his associates reorganized the company, and the firm name was changed to the Electric Controller and Manufacturing Company, with Mr. Eastwood as active head of both the financial and engineering phases of the business. He was the patentee of nearly one hundred inventions, covering all phases of electrical control and power generation. One of his most important achievements was the lifting magnet. The development of this appliance, which has saved the steel industry many millions of dollars, was entirely Mr. Eastwood's work. His inventive ability, while great, was less of a factor in his success than his winning personality and strong character, which enabled him to build up an organization of devoted and loyal assistants. Mr. Eastwood was first elected to membership in the Institute as an Associate on March 27, 1903, and was transferred to the grade of Fellow April 9, 1913.

CHARLES HENRY GUCKEL, Mem. A. I. E. E., of Springfield, Missouri, died November 1, 1916, as a result of injuries received the day before from a train in a railroad yard in Springfield, where he was engaged in superintending the installation of electrical equipment for a new turntable. Mr. Guckel was born in Düsseldorf, Germany, December 21, 1876, and was brought to this country when three

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years old, when his family settled in Pennsylvania. Mr. Guckel's first employment was with the Westinghouse Electric and Manufacturing Company, for three and a half years. He became general superintendent of the New York and Queens Electric Light Company at Flushing, New York, where he remained for more than three years. He spent eight years in the Panama Canal Zone and went from there in 1908 to Dover, New Jersey, as the general manager of the Dover Electric Light Company and the Rockaway Light and Improvement Company. In 1912 Mr. Guckel went to Springfield, Missouri, to become general manager of the Springfield Traction Company and the Springfield Gas and Electric Company. He resigned this position about a year ago to enter the field of general electrical contracting. Mr. Guckel was elected an Associate of the Institute on May 18, 1909, and was transferred to the grade of Member March 14, 1913.

JOHN ARNOLD BARRETT, Assoc. A. I. E. E., inventor and electrical engineer, associated for many years with the American Telephone and Telegraph Company, died November 9, 1916, after a long illness, at his home in Maplewood, New Jersey. Mr. Barrett was in his fifty-eighth year. He was born in Woodstock, Vermont, and educated at Dartmouth and Middlebury Colleges. From 1882 to 1884 he was associated with the Western Union Electric Company, and founded the the firm of Barrett Brothers. In 1886 he was employed by the American Telephone and Telegraph Company to overcome the difficulties with "cross-talk" on the first long-distance telephone line, from New York to Philadelphia. He invented the transposition system, which remedied the troubles, and is now used the world over. Mr. Barrett's next business venture was the organization of the Elektron Company, of which he was the first president, and which built the first electric storage battery automobile. In 1890 he rejoined the engineering staff of the American Telephone and Telegraph Company, and since then had played an important part in its work. Mr. Barrett is credited with being the first man to use paper insulation. He was elected an Associate of the Institute January 27, 1905.

RECOMMENDED FOR TRANSFER NOVEMBER 2, 1916

The Board of Examiners, at its regular monthly meeting on November 2, 1916, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

TO THE GRADE OF MEMBER

JONES, REGINALD L., Transmission Engineer, Western Electric Co., New York, N. Y.

KEELER, N. B., Junior Electrical Engineer, Fort Drum, P. I.

LENT, WILMAR F., Electrical Engineer, Cutler-Hammer Mfg. Co., New York, N. Y.

MEMBERS ELECTED NOVEMBER 10, 1916

BORGER, JOHN JAY, Electrical Superintendent, Augusta-Aiken Railway and Electric Corp., Terminal Bldg., Augusta, Ga.

HARVEY, CHARLES HENRY, President, Knoxville Railway & Light Co.; res., 626 Gay St., Knoxville, Tenn.

ASSOCIATES ELECTED NOVEMBER 10, 1916

BARTLETT, HAROLD WILMOT, Electrical Engineer, Preston School of Industry, Ione, Cal.

BULLARD, WILLIAM RALPH, Cadet Engineer, United Electric Light & Power Co.; res., 2 Nagle Ave., New York, N. Y.

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*COWIN, STUART H., Railway Div. Engineering Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh; res., 500 Todd St., Wilkinsburg, Pa.

*D'ALTON, F. KEITH, Electrical Engineer, Motor Sales Dept., Canadian General Electric Co., Toronto; res., Weston, Ontario.

EGAN, LEONARD W., Assistant Steam and Electrical Engineer, Pittsburgh Crucible Steel Co., Midland, Pa.; res , 1445 E. 84th St., Cleveland, O.

FARQUHAR, JOHN FREDERICK, Commercial Dept., Washington Water Power Co.; res., E. 36-27th Ave., Spokane, Wash.

*FISHER, SYDNEY, Electrical Engineer, Remington Arms and Ammunition Co.; res., 25 Sanford Ave., Bridgeport, Conn.

GASTMEYER, ROBERT WILLIAM, Designer on Transmission Lines, Chile Exploration Co., New York; res., 293 Evergreen Ave., Brooklyn, N. Y.

GLIENKE, HENRY E. J., Chief Electrican, Chicago, Milwaukee & St. Paul R. R. Co.; res., 848 No. Avers Ave., Chicago, Ill.

GREGORY, JOHN E., Electrical Engineer, The United Electric Co., Canton; res., 495 E. 125th St., Cleveland, O.

*GRIGSBY, OWEN EUGENE, Electrical Engineer and Works Manager, Benjamin Electric Co. Ltd., 1A Rosebury Ave., London, E. C., England.

*HAGUE, ALFRED EARLY, Telephone Engineer, Western Electric Co., 463 West St., New York, N. Y.

HENGSTENBERG, PAUL M., In charge of Experimental Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh; res., 1217 Mill St., Wilkinsburg, Pa.

HOUGH, ROBERT HARBISON, Consulting Engineer, 1222 Markoe St., Philadelphia, Pa.

JANSON, GEORGE WILLIAM, Engineering Assistant, Engineering Dept., Western Union Telegraph Co., New York; res., 358 Palmetto St., Brooklyn, N.Y.

KLEIN, FEDERICO, Chief Engineer, Cia. de Alumbrado Electrico, San Salvador, Salvador, Central America.

KOMIYA, JIRO, Electrical Engineer, Imperial Government Railways of Japan, Tokyo, Japan.

LEITNER, FRED L., General Storekeeper, Edison Elec. Ill. Co. of Brooklyn, 14 Rockwell Place, Brooklyn, N. Y.

*LENTZ, ROSCOE VERNON, Manager, Leeton Electric Co., Leeton, Mo.

LIONBERGER, HARVEY L., Construction Foreman and Engineer, 2718 Manito Boulevard, Spokane, Wash

LIPSCOMB, WILLIAM H., Salesman, United States Steel Products Co., 30 Church St., New York, N. Y.

MACY, HENRY D., Chief Engineer with Thomas F. Ryan, Oak Ridge, Va.

MCCONNELL, JOHN JAMES, Supt., Rayville Light & Water Plant, Rayville, La.

*MOORE, CHARLES JOEL, Instructor in Electrical Engineering, School of Engineering, Oklahoma A. & M. College; res., 224 Duncan St., Stillwater, Okla.

MORSE, ROBERT EMERY, Electrical Engineer, Cerro de Pasco Mining Co., La Fundicion, Peru, South America.

ODENDAHL, ROBERT, Electrician, Canadian Copper Co., Frood Mine, via Sudbury, Ontario.

OLIVER, ALEXANDER DIEZ, General Inspector of Lighting Dept., Havana Central Railroad Co., Terminal Station, Havana, Cuba.

PRESTON, CHARLES RAYMOND, Field Engineer, Texas Power & Light Co.; res., 4933 Crutcher St., Dallas, Texas.

ROBERTSON, ARCHIBALD JOHNSON, Superintendent of Eastern Division, Mt. Whitney Power & Electric Co., Visalia, Cal.

ROE, CHARLES HARVEY, Superintendent, M. & S. Electric Co., 617 South Saginaw St., Flint, Mich.

SCHINDLER, ROBERT A., Draughtsman, Cutler-Hammer Mfg. Co.; res., 174 13th St., Milwaukee, Wis.

*SEEGER, EDWIN WILBUR, Engineering Department, Cutler-Hammer Mfg. Co.; res., 85-17th St., Milwaukee, Wis.

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SHAVER, JOHN H., Testing Dept., Diehl Mfg. Co., Elizabethport; res., 117 Armstrong Ave., Jersey City, N. J.

SHEVALIN, VADIM A., Russian Government Inspector; Eddystone Ammunition Corp., Eddystone, Pa.

SHINGAI, KAN-ICHI, Teacher, Denkigakko Kanda, Tokyo, Japan.

SLUTTER, WALDRON, Assistant Superintendent, Vinton Colliery Co., Vintondale, Pa.

STAPLES, WILLIAM DEERING, Division Supt. of Plant, American Tel. & Tel. Co., 430 Gates Bldg.; res., 1007 Linwood Blvd., Kansas City, Mo.

STOCKBERGER, MYRON HOY, Engineering Dept., Western Union Telegraph Co., 195 Broadway, New York; res., 160 Stratford Road, Brooklyn, N. Y.

STONE, ROBERT R., Resident Engineer, American Gas & Electric Co.; res., 101 14th St., Wheeling, W. Va.

SWARTZ, TASSO W., Supt., Underground Service Construction, Spokane Heat, Light & Power Co., Spokane, Wash.

THOMS, ALEXANDER P., Assistant Superintendent of Street Dept., Commonwealth Edison Co., 72 W. Adams St., Chicago, Ill.

THOMSON, CHARLES S., Electrical Engineer, District Manager, Vickers Ltd., Vickers House, Broadway, Westminster, London, S. W., England.

VAN AERNAM, J. H., Sales Agent, General Electric Co.; res., 508 Ivy St., Pittsburgh, Pa.

VAN NIEUKERKEN, JOHANNES MARINUS, Correspondent, Westinghouse Electric Export Co., East Pittsburgh, Pa.

WAGNER, GEORGE ERNST, Superintendent of Distribution, Madison Gas & Electric Co., 120 E. Main St., Madison, Wis.

WEBER, RUDOLF LORENZ, Engineer of Equipment & Power, Board of Control, Kansas City Railways Co., 1500 Grand Ave., Kansas City, Mo.

*WOOD, LEON FOREST, Instructor in Telephone Engineering, University of Oklahoma, Norman, Okla.

Total 47.

*Former enrolled Students.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before December 31, 1916.

Aldrick, L. C., E. Springfield, Mass.
Atwell, C. A., Urbana, Ill.
Battin, W. I., Ft. Wayne, Ind.
Baxter, H. C., Philadelphia, Pa.
Baxter, H. K., Boston, Mass.
Beary, D. B., New York, N. Y.
Beaver, G. L., Schenectady, N. Y.
Bellville, J. R., St. Louis, Mo.
Bessesen, B. B., Seattle, Wash.
Bireley, J. F., Ft. Wayne, Ind.
Bressler, H. V., Philadelphia, Pa.
Brockway, R. M., Schenectady, N. Y.
Brown, C. C., San Francisco, Cal.
Burnham, R. R., Boston, Mass.
Burns, T. S., Elmira, N. Y.
Butler, P. H., New York, N. Y.
Cameron, G., South Boston, Mass.
Clarke, E. C., Philadelphia, Pa.
Cole, H. L., East Pittsburgh, Pa.
Cornell, R. L., Hazard, Ky.
Curtis, R. L., Detroit, Mich.
Dace, F. E., Akron, O.
De Camp, R. E., East Pittsburgh, Pa.
Dhooge, V. C., Detroit, Mich.
Diehl, G. S., Pittsburgh, Pa.
Dixon, H. J., New York, N. Y.
Dunlap, H. B., McGill, Nev.
Edison, O. E., Chicago, Ill.
England, P. D., Auckland, N. Z.
Faden, J. L., Boston, Mass.
Fairbanks, F. B., East Pittsburgh, Pa.
Ganschow, L. W., Cleveland, O.
Goetzenberger, R.L., Schenectady, N.Y.
Gooch, E. P., East Pittsburgh, Pa.
Grossbard, S., New York, N. Y.
Hansen, K. L., East Pittsburgh, Pa.
Harold, W. H., Walla Walla, Wash.
Hauser, W. S., Newark, N. J.

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Hausmann, V. F., Philadelphia, Pa.
Hoglund, G. E., Ft. Wayne, Ind.
Holmes, W. M., Los Angeles, Cal.
Hoppin, G. H., Wilkes-Barre, Pa.
Horiuchi, S., Boston, Mass.
Hosegood, P. E., Schenectady, N. Y.
Hudson, W. F., Schenectady, N. Y.
Huling, J. E., Jr., East Pittsburgh, Pa.
Huxley, R. D., New York, N. Y.
Imes, O. S., Milwaukee, Wis.
Inglis, J. J. (Member), Motherwell, Scotland
Johnson, H. A. (Member), Chicago, Ill.
Johnson, S. F., Worcester, Mass.
Johnson, T. D., Birmingham, Ala.
Kent, P. J., Detroit, Mich.
Kester, H. J., Buffalo, N. Y.
Kilby, H. S., St. Louis, Mo.
Kirk, J. B., New York, N. Y.
Knowlton, A. E. (Member), Hartford, Conn.
Kranz, H. E., Madison, Wis.
Krug, F., Socorro, N. M.
Lanning, J. G., Bridgeport, Conn.
Latimer, C. W., Louisburg, N. S.
Laue, G. E., Milwaukee, Wis.
Leavitt, A. R., Duquesne, Pa.
Lininger, C. R., Chicago, Ill.
Little, C. B., New York, N. Y.
Mailhouse, R. J., Youngstown, O.
Marcum, T. E., Great Falls, Mont.
Marcy, C. G., Schenectady, N. Y.
Markham, A. J., New York, N. Y.
Marvin, H. B., Schenectady, N. Y.
McLennan, J. C. E., Philadelphia, Pa.
McNabb, G. C., Philadelphia, Pa.
Miller, S. G., New Bedford, Mass.
Mittenthal, N. J., Schenectady, N. Y.
Moon, F. L., East Pittsburgh, Pa.
Moore, A. W., Scranton, Pa.
Morgan, N. L., Louisburg, N. S.
Muehleman, H. J., Toronto, Ont.
Nash, J. F., Pittsfield, Mass.
Nikiforoff, B., Schenectady, N. Y.
O'Hagen B. E., Swissvale, Pa.
Ordonez, B. R., Urbana, Ill.
Painten, A. M., East Cambridge, Mass
Phelps, H. E., Lafayette, Ind.
Pollock, J. D., Portland, Ore.
Polster, M. A., Baltimore, Md.
Ransom, C. A., Hoboken, N. J.
Rasch, G. A., Baltimore, Md.
Ringstrom, I. G., St. Paul, Minn.
Ritter, R. W., Philadelphia, Pa.
Roberts, H. G., Trail, B. C.
Rogers, C T., Charleston, W. Va.
Schlesinger, I. S., Gloucester, N. J
Sclater, R. H., Atlanta, Ga.
Selden, G. K., Atlanta, Ga.
Senior, D. B., New York, N. Y.
Sewell, G. L., Chicago, Ill.
Sheffler, M., Hartford, Conn.
Small, J. C. M., Niagara Falls, Ont.
Smith, H. J. (Fellow), Asuncion, Paraguay
Smith, H. L., East Pittsburgh, Pa.
Smith, W. H., East Pittsburgh, Pa.
Snyder, E. B., Mansfield, O.
Soderstrom, C. A., Denver, Colo.
Spence, J. Glasgow, Scotland
Sprague, C. W., Great Falls, Mont.
Spurgeon, J. H., City Point, Va.
Stack, A. H., Dennison, O.
Stege, F. H., Jr., East Rutherford, N. J.
Stevens, H. W., Milwaukee, Wis.
Strecker, G. M., East Pittsburgh, Pa.
Street, L. N., New York, N. Y.
Sweitzer, L. E., Pittsfield, Mass.
Taylor, D. W., Newark, N. J.
Thompson, J. E., Richmond, Va.
Tizley, A.J. (Member), New York, N.Y.
Trone, S., Schenectady, N. Y.
Welker, J. A., Butler, Pa.
Wentworth, H. H., East Pittsburgh, Pa.
Werth, J. R. (Member), Schenectady, N. Y.
Whiting, B. I., Chicago, Ill.
Williams, E. E., Schenectady, N.Y.
Worden, M. W., Ft. Wayne, Ind.
Zehr, V. A., East Pittsburgh, Pa.
Total 124

STUDENTS ENROLLED NOVEMBER, 10, 1916

8302 Thomas, M. A., Univ. of Penna.
8303 Weaver, R.L., Carnegie Inst. Tech.
8304 Blaikie, R. C., Wentworth Inst.
8305 Scrimgrour, W. B., A. & M. College of Texas.
8306 Ebert, S. B., Univ. of Minnesota
8307 Friedberg, H., Carnegie Inst. Tech.
8308 Morley, A. L., Carnegie Inst. Tech.
8309 Stiers, F. G., Colo. Agri. College
8310 Young, L. F., Finlay Engg. College
8311 Campbell, I.S., Ohio Northern Univ.

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8312 Hoffman, R. A., Univ. of Okla.
8313 White, G., Univ. of Oklahoma.
8314 Erickson, A. E., Univ. of Okla.
8315 Wheatley, J. A., Univ of Okla.
8316 Whitwell, C. H., Univ. of Okla.
8317 Balyeat, R. H., Univ. of Okla.
8318 Pigg, A. M., Univ. of Okla.
8319 Steedman, A. E., Univ. of Okla.
8320 Heller, G. N., Univ. of Okla.
8321 Richards, H. M., Univ. of Okla.
8322 Heffner, R. E., Univ. of Okla.
8323 Hughes, C. T., Univ. of Okla.
8324 Walter, O. W., Univ. of Okla.
8325 Freeman, E. D., Univ. of Okla.
8326 Watkins, I. B., Univ. of Okla.
8327 Busby, W. W., Univ. of Okla.
8328 Reid, L., Univ. of Okla.
8329 Richards, R. C., Colo. Agri. Coll.
8330 Maynard, A. C., Univ. of Calif.
8331 Kleinman, H.A., Armour Inst. Tech.
8332 Stryker, C. E., Armour Inst. Tech.
8333 Watt, W. T., Armour Inst. Tech.
8334 Goldstein, J.N., Armour Inst. Tech.
8335 Stevers, H. D., Armour Inst. Tech.
8336 Welch, O. L., Armour Inst. Tech.
8337 Weston, H., Armour Inst. Tech.
8338 Muelleman, J.P., Armour Inst. Tech.
8339 Bacon, M. F., Armour Inst. Tech.
8340 Matejka, G., Armour Inst. Tech.
8341 Gulledge, J. S., Kansas State Agri. Coll.
3842 Graves, R.A., Kans. State Agri. Coll.
8343 Witham, C. R., Kans. State Agri. Coll.
8344 Lemly, P.R., Kans. State Agri. Coll.
8345 Durland, M. A., Kans. State Agri. Coll.
8346 Franklin, R. E., Kans. State Agri. Coll.
8347 Van Trine, R. A., Kansas State Agri. Coll.
8348 Williams, H. A., Kans. State Agri. Coll.
8349 Russell, M. H., Kans. State Agri. Coll.
8350 Soule, M.H., Kans. State Agri. Coll.
8351 Baldwin, L. E., Kans. State Agri. Coll.
8352 Miller, O. R., Kans. State Agri. Coll.
8353 Puckett, J. L., Kans. State Agri. Coll.
8354 Cunningham, G. A., Kansas State Agri. Coll.
8355 Wallerstedt, C. A., Kansas State Agri. Coll.
8356 Hindman, O. A., Kansas State Agri. Coll.
8357 Tubbs, L. G., Kansas State Agri. Coll.
8358 Scriven, F.T., Kans. State Agri. Coll.
8359 Thackvey, W. L., Kansas State Agri. Coll.
8360 Alford, L. G., Kansas State Agri. Coll.
8361 McGraw, W. C., Kansas State Agri. Coll.
8362 Ernsting, W. C., Kansas State Agri. Coll.
8363 Oliver, R. H., Kansas State Agri. Coll.
8364 Gannett, D., Univ. of Minnesota
8365 Swain, R. B., Mass. Inst. Tech.
8366 Dunlap, L. J., Univ. of Minn.
8367 Devin, W. C., Va. Poly. Inst.
8368 Hagy, B. E., Va. Poly. Inst.
8369 Barton, E. M., Va. Poly. Inst.
8370 Gillette, C. C., Bucknell Univ.
8371 Speece, R., Ohio Northern Univ.
8372 Jones, H. M., Univ. of Kansas.
8373 Norton, P. T., Jr., Univ. of Wis.
8374 Lehmkuhl, F., Mass. Inst. Tech.
8375 Watson, C. J., Highland Park Coll.
8376 Wegmann, C. A., Highland Park Coll.
8377 Aimutis, F. J., Ohio North. Univ.
8378 de Barros, E. S., Ohio No. Univ.
8379 Flanigen, J. M., Ga. School Tech.
8380 Goldhammer, C. J., Univ. of Wis.
8381 Rath, E. R., Univ. of Pittsburgh.
8382 McWherter, M. C., Univ. of Pittsburgh.
8383 Nelson, L. V., Univ. of Wis.
8384 Robinson, R. E., Ga. Sch. Tech.
8385 Briers, E. H., West Va. Univ.
8386 Cronin, D. F., West Va. Univ.
8387 Thorn, M. H., West Va. Univ.
8388 Montgomry, J. G., West Va. Univ.
8389 Longanecker, C.L., West Va. Univ.
8390 Gilchrist, M.C., State Univ. of Iowa.
8391 Farago, J., Ga. School of Tech.
8392 Rice, T. G., Univ. of Kentucky
8393 Moore, W. S., Univ. of Kentucky
8394 Borders, L. S., Univ. of Kentucky

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8395 McNamara, J. E., Univ. of Ky.
8396 Waters, J. N., Univ. of Kentucky.
8397 Robertson, E. K., Univ. of Ky.
8398 Horme, H. P., Univ. of Kentucky.
8399 Davies, A. W., Univ. of Kentucky.
8400 McClanahan, L. C., Univ. of Ky.
8401 Aaron, G. D., Univ. of Kentucky.
8402 Montgomery, M. M., Univ. of Ky.
8403 Smiser, H. C., Univ. of Ky.
8404 Drake, E. E., Univ. of Kentucky.
8405 Eimer, A. L., Univ. of Kentucky.
8406 Penn. E. S., Univ. of Kentucky.
8407 Springer, D. S., Univ. of Ky.
8408 Scott, J. G., Univ. of Ky.
8409 Swenson, G. W., Univ. of Minn.
8410 Werth, C. W., Oregon Agri. Coll.
8411 Newlander, R. A., Armour Inst. of Technology.
8412 Hofgren, A. A., Armour Inst. Tech.
8413 Moore, E. A., Jr., Armour Inst. of Technology.
8414 Ferguson, A. H., Armour Inst. Tech.
8415 Senescall, C., Armour Institute of Technology.
8416 Beaumont, E. S., Armour Inst. of Technology.
8417 Jalonack, H. M., Syracuse Univ.
8418 Clark, L. T., Univ. of So. Cal.
8419 Nathan, W. S., Univ. of Wis.
8420 Plank, H. H., Clarkson College of Technology.
8421 Dodge, C. C., Univ. of Wis.
8422 Havel, F., Univ. of Washington.
8423 Glover, F. A., Highland Park Coll.
8424 Morse, L. R., Highland Park Coll.
8425 Jacobson, O., Highland Park, Coll.
8426 Flader, F. E., Highland Park Coll.
8427 Smith, H. A., Univ. of Minnesota.
8428 Bumstead, S. W., Univ. of Toronto.
8429 Tuttle, H. A., Univ. of Toronto.
8430 Smithson, E. W., Univ. of Toronto.
8431 Brown, H. S., Univ. of Toronto.
8432 Titus, O. W., Univ. of Toronto.
8433 Gram, J. I., Univ. of Toronto.
8434 Fisher, J. C., Mass. Inst. Tech.
8435 Gill, L. M., Brooklyn Poly. Inst.
8436 Bancker, E. H., Mass. Inst. Tech.
8437 Locknow, L. L., Purdue Univ.
8438 Feder, J. B., Purdue University.
8439 Gaskill, L. B., Purdue Univ.
8440 Mitchell, F. K., Purdue Univ.
8441 Smith, P. C., Purdue Univ.
8442 Branson, D. E., Purdue Univ.
8443 Havens, C. B., Purdue Univ.
8444 Rowland, W. B., Purdue Univ.
8445 Rogers, G. M., Purdue Univ.
8446 Littell, J. E., Purdue Univ.
8447 Wells, W. B., Purdue, Univ.
8448 Dye, R. M., Purdue Univ.
8449 Deane, T. Y., Purdue Univ.
8450 Dart, H. F., Purdue Univ.
8451 Stafford, J. W., Purdue Univ.
8452 Miller, L. W., Purdue Univ.
8453 Wright, R. H., Purdue Univ.
8454 Doerfler, T. E., Highland Park College.
8455 Saxe, P. A., Highland Park Coll.
8456 Knause, D. G., Highland Park Coll.
8457 Pierce, W. H., Highland Park Coll.
8458 Jensen, O. M., Highland Park Coll.
8459 Lease, C. J., Highland Park Coll.
8460 Idail, M. J., Catholic Univ. of America.
8461 Evans, J. H., Univ. of Ky.
8462 Lee, C. F., Univ. of Kentucky.
8463 Foeste, A. B., Univ. of Wis.
8464 Shippy, V. Z., Univ. of Penna.
8465 Blanding, F. A., Syracuse Univ.
8466 Mason, H. E., Syracuse Univ.
8467 Welch, D. W., Syracuse Univ.
8468 Cappon, M. T., Syracuse Univ.
8469 Coelho, J. G., Syracuse Univ.
8470 Rosenkrans, H. D., Syracuse Univ.
8471 Klumbach, H. R., Syracuse Univ.
8472 Bowman, H. L., Syracuse Univ.
8473 Eberhardt, W. W., Syracuse Univ.
8474 Pomeroy, W. D., Syracuse Univ.
8475 Epstein, D. N., Syracuse Univ.
8476 Stern, A. G., Univ. of Penna.
8477 Truran, W. W., Univ. of Wis.
8478 Ferguson, T., Univ. of Texas.
8479 Gadberry, J. L., Univ. of Texas.
8480 Walker, L. B., Univ. of Texas.
8481 Seebe, A., Univ. of Texas.
8482 Fisher, G. W., Kans. State Agri. Coll.
8483 Leydig, R. B., Kans. State Agri. Coll.
8484 Kesinger, E. V., Kans. State Agri. Coll.
8485 Predock, N. H., Washington Univ.

Total 184

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EMPLOYMENT DEPARTMENT

Note: Under this heading brief announcements (not more than fifty words in length) of vacancies, and men available, will be published without charge to members. Copy should be prepared by the member concerned and should reach the Secretary's office prior to the 20th of the month. Announcements will not be repeated except upon request received after an interval of three months: during this period names and records will remain in the office reference files. All replies should be addressed to the number indicated in each case, and mailed to Institute headquarters.

The cooperation of the membership by notifying the Secretary of available positions, is particularly requested.

VACANCIES

V-171. Chemical Engineer with experience in organizing plant for position as departmental engineer in dye works. Please give full details of experience and salary expected.

V-182. Electro-Physicist with inclination towards engineering research and development, or electrical engineer with broad physical laboratory experience, wanted by a prominent specialty concern in the Middle West. Good opportunity for a man of ability and initiative. State full particulars in first letter.

V-183. An electrical contracting firm in New York City has an opening for a technical graduate to do estimating and engineering work. Must be accurate and preferably have had one or two years' experience in the General Electric or Westinghouse testing departments.

V-185. Electrical Engineer wanted as assistant to construction engineer. Must be technical graduate with some experience in design and construction work on a-c. substations, power houses and subways. Give experience and state salary expected. Permanent position to right man.

V-187. Opportunity for engineer or draftsman, who has had experience with electric railway installations, including catenary overhead, or who has had two or three years' experience in general engineering work.

The U. S. Civil Service Commission announces an examination to be held at numerous places in the United States on December 13-14, for Assistant Engineer Inspectors of Weights and Measures. Technical graduates or students in their senior year are eligible. Those interested should apply to the Commission in Washington, D.C., for circular No. 1547 describing the examination and application form No. 1312.

MEN AVAILABLE

605. Electrical Engineer, age 25, married. Canadian Westinghouse apprenticeship course, motor and transformer testing departments; 3½ years' experience in operation, maintenance, construction and superintendence of hydroelectric plants; also experience in sales and meter work. Desire position as superintendent or assistant electrical engineer with a medium size hydroelectric system. At present in charge of small system.

606. Electrical Engineer, Cornell graduate (1915), since employed by large central station concern, desires position with engineering firm or manufacturer located in or near Chicago. Also will invest several thousand dollars in the right project.

607. Draftsman, 22, mechanical, electrical engineering student; experienced in detailing, sketching, layout work, etc., desires position in New York City.

608. Engineer-Manager, with ten years' utility experience, desires opening where intelligence, energy, capacity and business sense added to Cornell training will be of use. Experience includes design, operating, commercial and responsible executive work with modern electrical power systems. Position of responsibility, commercial engineering preferred, with progressive engineering, utility or industrial concern desired.

609. Graduate Electrical Engineer, degrees A.M. and B.S., experienced in the design, construction and operation of 4000- and 13,000-volt transmission and distribution systems. At present engaged in the manufacture of electrical supplies, but desires to get back into transmission work.

610. Electrical-Mechanical Engineer, Austrian university graduate; naturalized American. Two years electrical

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machinery designing, five years estimating, designing of entire electrical plants, transmissions, distribution systems and equipment abroad. Switchboard, station layout and drafting with Westinghouse and General Electric, three years with each. German, French, working knowledge of Spanish. Will go anywhere.

611. Do you want a young man, a little above the ordinary, with five years' experience along electrical and mechanical lines, including railway and contracting experience? Technical graduate desires to locate with some company where hard work, ability and sticking to it are rewarded by promotion.

612. Engineer, technical education, now employed on engineering corps of large telephone company, wishes to become associated with company, either power or telephone, desirous of services of an active, outside plant engineer who has knowledge of layouts and distribution systems; also capable of building up or reorganizing the plant.

613. Well-known American sales engineer, with over twenty years' experience, now holding important position, considers changing. Thoroughly posted on European and American practise in power transmission, station design and switchgear. Graduate two universities; Fel. A. I. E. E. Thorough designer. Successful business getter. Speaks French, some Spanish and Italian. Posted on export work.

614. Engineer, power house and substation construction, open for engagement January 1. Age 30.

615. Graduate in electrical engineering desires position with contracting firm doing actual construction, or with managing and operating concern (railways, power plants, etc.) Experience in street railway investigations and reports, arc lighting, steam engine tests, high- and low-tension substation work. At present employed with Eastern railroad. Age 28. Middle West preferred.

616. Cost Accountant and Auditor, with experience also as Secretary and Treasurer, desires to change. Employed at present installing cost system in manufacturing plant. Thoroughly familiar with corporation accounts.

617. Mechanical and Electrical Engineer desires a sales position in some high-grade engineering line in New York City and vicinity. Good personality and accustomed to meeting all classes of people. Fourteen years' experience; has held responsible positions, in the design, construction, operation and management of power stations, electric lighting and railway properties, transmission lines and machine shop practise. Can arrange for interview at any time.

618. Chief Electrician, technical graduate, age 31, married. Thirteen years' practical experience installing and maintaining a-c. and d-c. electrical machinery.

619. Construction or Maintenance Engineer, 24 years' experience in electric railway and lighting construction and operation, chiefly in the railway field. Has specialized in power and substation and overhead construction. Available at short notice. Now employed. Will go anywhere.

620. Electrical Engineer, five years in charge of the electrical engineering work of a large central station company. Experienced in design, construction and maintenance. Equipment and men efficiently handled. Technical graduate married; best of reasons for change.

621. Electrical Engineer, of 20 years' experience excellent record, desires position as electrical engineer, or chief electrician. Can fill position of manager or superintendent of good size plant, high- or low-tension. Telephone systems, regular or automatic. Good appearance and knows how to handle the public. Position more than salary desired.

622. An electrical engineer with experience and scientific training seeks opportunity to develop a research or testing department for an industrial or utility corporation.

623. Executive, Mechanical-Electrical Engineer, age 42. General Superintendent of city system with 50,000 meters. Formerly in charge of group of suburban towns. Intimate knowledge of efficient public utility operation, both in office and in field. Desires position in line with past experience. Minimum salary, $3,000.

624. Mechanical and Electrical Engineer, desires position with manufacturing or public service company. New York or vicinity. University graduate; age 36, experienced executive and buyer.

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ACCESSIONS TO LIBRARY

This list includes books on electrical subjects only, which have been added to the library of the A. I. E. E. and the U. E. S. during the past month, not including periodicals and other exchanges.

Carrying capacity of underground power cables. By H. Matsumoto. (Report No. 24 of the 3d section, Electro-Technical Laboratory, Tokio, Japan). Tokio, 1916. (Gift of Electro-Technical Laboratory.)

Chicago Traction. Board of Supervising Engineers. Annual Report 7th, 1914. Chicago, 1916. (Gift of Bion J. Arnold.)

Disk-type strain and pin supported insulators. (Reprinted from "Electrical World" May 6, 1916) (Gift of Electrose Mfg. Co.)

List of Inspected Electrical Appliances. October 1916. (Gift of Underwriters Laboratories.)

Eene Rijks-Electriciteits Voorziening van Nederland. By H. Doyer. Delft, 1916. (Gift of author.)

——Bijlagen I-X behoorende bij. By H. Doyer. (Gift of the author.)

Hawkins Electrical Guide. Number 10, Questions, answers and illustrations. New York, 1916. (Exchange.)

Improved disk strain and pin type insulators invented by Louis Steinberger. (Reprinted from "Electrical Review & Western Electrician" June 17, 1916). (Gift of Electrose Mfg. Co.)

UNITED ENGINEERING SOCIETY

Applied Electricity for Practical Men. By A. J. Rowland. New York, 1916. (Purchase.)

Electric Power Club. Executive Staff, Member Companies, Committees, Constitution and By-Laws, etc. Aug. 1, 1916. (Gift of Club.)

Electrical Engineering—Advanced Course. By E. J. Berg. New York, 1916. (Purchase.)

Engineering manual of the American Electric Railway Engineering Association, revised Dec. 1915. (Purchase.)

Handbook of Machine Shop Electricity. By C. E. Clewell. New York, 1916. (Purchase.)

List of Inspected Electrical Appliances, published List of Inspected Electrical Appliances, published by Underwriters Laboratories. April, 1916. Chicago, 1916. (Purchase.)

Principles of Alternating-Current Machinery. By R. R. Lawrence. New York, 1916. (Purchase.)

Wireless Course in Twenty Lessons. By H. W. Secor and others. New York Electro Importing Co., 1915. (Gift of Publishers.) A text book for the beginner in wireless. W.P.C.

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OFFICERS AND BOARD OF DIRECTORS, 1916-1917.

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(Term expires July 31, 1918)
JOHN J. CARTY

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BANCROFT GHERARDI
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*FRANKLIN L. POPE, 1886-7.
T. COMMERFORD MARTIN, 1887-8.
EDWARD WESTON, 1888-9.
ELIHU THOMPSON, 1889-90
*WILLIAM A. ANTHONY, 1890-91.
ALEXANDER GRAHAM BELL, 1891-92
FRANK JULIAN SPRAGUE, 1892-3.
*EDWIN J. HOUSTON, 1893-4-5.
*LOUIS DUNCAN, 1895-6-7.
FRANCIS BACON CROCKER, 1897-8.
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CARL HERING, 1900-1.
CHARLES P. STEINMETZ, 1901-02
CHARLES F. SCOTT, 1902-3.
BION J. ARNOLD, 1903-4
JOHN W. LIEB, 1904-5
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SAMUEL SHELDON, 1906-7.
HENRY G. STOTT, 1907-8
LOUIS A. FERGUSON, 1908-09.
LEWIS B. STILLWELL, 1909-10.
DUGALD C. JACKSON, 1910-11.
GANO DUNN, 1911-12.
RALPH D. MERSHON, 1912-13.
C. O. MAILLOUX, 1913-14.
PAUL M. LINCOLN, 1914-15.
JOHN J. CARTY, 1915-16.

*Deceased.

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John J. Carty,	H. H. Porter,
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Term expires July 31, 1917.

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Term expires July 31, 1919.

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Term expires July 31, 1920.

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Term expires July 31, 1921.

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Term expires July 31, 1917.

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Term expires July 31, 1918.

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Wm. Maver, Jr.,
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Graham Bright,
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F. J. Duffy,
L. C. Ilsley,
R. L. Kingsland,
Charles Legrand,
Charles M. Means,
K. A. Pauly,
H. M. Warren.

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Box 242, East Liberty, Pa.

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F. B. Crosby,
E. Friedlaender,
E. S. Jefferies,
D. M. Petty,
A. G. Pierce,
J. C. Reed,
R. Tschentscher,
Brent Wiley,
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Revised to December 1, 1916.

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A. S. McAllister, J. Franklin Stevens,
N. W. Storer.

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Ralph D. Mershon, Charles W. Stone.

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Gano Dunn, A. S. McAllister,
Schuyler Skaats Wheeler.

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H. H. Barnes, Jr., Gano Dunn,
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Samuel Sheldon, W. I. Slichter,
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Denver.....May 18, '15	H. S. Sands	Robert B. Bonney, 806 Telephone Building, Denver, Colo.
Detroit-Ann Arbor.....Jan. 13, '11	A. A. Meyer	A. Oakes, American Electrical Heater Company, Detroit, Mich.
Fort Wayne.....Aug. 14, '08	J. J. Kline	
Indianapolis-Lafayette..Jan. 12, '12	J. L. Wayne, 3rd	Walter A. Black, 3042 Graceland Ave., Indianapolis, Ind.
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Kansas City, Mo......Apr. 14, '16	Gordon Weaver	Glenn O. Brown, 5519 Tracy Ave., Kansas City, Mo.
Los Angeles.....May 19, '08	R. H. Manahan	Carl E. Johnson, 459 East Third Street, Los Angeles, Cal.
Lynn.....Aug. 22, '11	Gordon Campbell	M. B. Carroll, Gen. Elec. Co., West Lynn, Mass.
Madison.....Jan. 8, '09	P. A. Kartak	L. E. A. Kelso, University of Wisconsin, Madison, Wis.
Mexico.....Dec. 13, '07		
Milwaukee.....Feb. 11, '10	P. W. Ells	H. P. Reed, Cutler-Hammer Mfg. Co., Milwaukee, Wis.
Minnesota.....Apr. 7, '02	R. J. S. Carter	Vernon S. Beck, Beck Elec. Const. Co., Minneapolis, Minn.
Panama.....Oct. 10, '13	Earl J. Atkisson	C. W. Markham, Balboa Heights, C. Z.
Philadelphia.....Feb. 18, '03	H. P. Liversidge	W. F. James, 14th Floor, Widener Bldg., Philadelphia, Pa.
Pittsburgh.....Oct. 13, '02	G. C. Hecker	F. E. Wynne, W. E. and M. Company, East Pittsburgh, Pa.
Pittsfield.....Mar. 25, '04	V. E. Goodwin	E. K. Shelton, General Electric Company, Pittsfield, Mass.
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Rochester.....Oct. 9, '14	O. W. Bodler	Lucien Buck, 1416 Lake Avenue, Rochester N. Y.
St. Louis.....Jan. 14, '03	W. O. Pennell	George McD. Johns, Room 401, City Hall, St. Louis, Mo.
San Francisco.....Dec. 23, '04	J. E. Woodbridge	A. G. Jones, 811 Rialto Building, San Francisco, Cal.
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Spokane.....Feb. 14, '13	D. F. Henderson	C. M. Fisher, Washington Water Power Company, Spokane, Wash.
Toledo.....June 3, '07	W. E. Richards	Max Neuber, Cohen, Freidlander & Martin, Toledo, Ohio.
Toronto.....Sept. 30, '03	E. T. J. Brandon	Wills Maclachlan, 910 Excelsior Life Building, Toronto, Ont.
Urbana.....Nov. 25, '02	I. W. Fisk.	L. V. James, Univ. of Illinois, Urbana, Ill.
Vancouver.....Aug. 22, '11	R. F. Hayward	T. H. Crosby, Canadian Westinghouse Co., Vancouver, B. C.
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Arkansas, Univ. of.....Mar. 25, '04	A. L. Wilson	W. L. Teague, University of Arkansas, Fayetteville, Ark.
Armour Institute.....Feb. 26, '04	Ralph H. Earle	Harold A. Kleinman, 7743 Burnham Avenue, Chicago, Ill.
Brooklyn Poly. Inst......Jan. 14, '16	Albert H. Bernhard	Walter J. Seeley, The Polytechnic Institute, Brooklyn, N. Y.
Bucknell University....May 17, '10	N. J. Rehman	E. C. Hageman, Bucknell University, Lewisburg, Pa.
California, Univ. of.....Feb. 9, '12	Marc Holzer	A. C. Maynard, University of California, Berkeley, Cal.
Carnegie Inst. of Tech...May 18, '15	E. G. Peterson	B. C. Dennison, Carnegie School of Technology, Pittsburgh, Pa.
Cincinnati, Univ. of.....Apr. 10, '08	R. L. Utley	H. V. McCormick, 3110 Woodburn Ave., Cincinnati, Ohio.
Clarkson Col. of Tech...Dec. 10, '15	H. H. Plank	Philip R. Cloke, Clarkson College of Technology, Potsdam, N. Y.
Clemson Agricultural Col. Nov. 8, '12	D. H. Banks	W. H. Neil, Clemson College, S. C.
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Highland Park College..Oct. 11, '12	E. E. Gould	Adolph Shane, Highland Park College, Des Moines, Iowa.
Idaho, Univ. of.....June 25, '14	D. Nankervis	L. J. Corbett, Univ. of Idaho, Moscow, Idaho.
Iowa State College.....Apr. 15, '03	C. L. Merrick	F. A. Robbins, Iowa St. Col., Ames, Iowa.
Iowa, Univ. of.....May 18, '09	H. W. Matson	A. H. Ford, University of Iowa, Iowa City, Iowa.
Kansas State Agr. Col...Jan. 10, '08	Walter E. Deal	G. B. McNair, Kansas State Agri. Col., Manhattan, Kansas.
Kansas, Univ. of.....Mar. 18, '08	N. M. Foster	G. M. Bowman, 1517 New Hampshire, Lawrence, Kansas.
Kentucky, State Univ. of Oct. 14, '10	H. E. Melton	Margaret Ingels, 251 Delmar Avenue, Lexington, Ky.
Lafayette College.....Apr. 5, '12	Samuel McC. Hunt	Carl Theodore Mack, 418 McCartney Street, Easton, Pa.
Lehigh University.....Oct. 15, '02	F. L. Magee	J. F. Wentz, Lehigh University, South Bethlehem, Pa.
Lewis Institute.....Nov. 8, '07	P. B. Woodworth	
Maine, Univ. of.....Dec. 26, '06	Fred P. Jones	G. K. Wadlin, Lambda Chi Alpha House, Orono, Maine.
Michigan, Univ. of.....Mar. 25, '04	A. N. Clarke	F. E. Richardson, University of Michigan, Ann Arbor, Mich.
Minnesota, Univ. of....May 16, '16	Jesse L. Thompson	Donald P. Loye, 4216 Dupont Ave., South Minneapolis, Minn.
Missouri Univ. of.....Jan. 10, '03	K. Atkinson	D. P. Savant, University of Missouri, Columbia, Mo.
Montana State Col.....May 21, '07	Carl Ladenburg	J. A. Thaler, Montana State College, Bozeman, Mont.
Nebraska, Univ. of.....Apr. 10, '08	Olin J. Ferguson	V. L. Hollister, Station A., Lincoln, Nebr.
North Carolina Col. of Agr., and Mech. Arts.....Feb. 11, '10	F. E. Coxe	R. M. Hooper, N. C. Coll. of A. and M. Arts, West Raleigh, N. C.
North Carolina, Univ. of.Oct. 9, '14	Edw. Y. Keesler	W. H. Joyner, Univ. of North Carolina, Chapel Hill, N. C.
Norwich University.....June 28, '16		
Ohio Northern Univ.....Feb. 9, '12	W. C. Bedell	W. W. Wickerham, 125 S. Gilbert Street, Ada, Ohio.
Ohio State University....Dec. 20, '02	H. D. Bender	L. W. Birch, 138 Wheatland Avenue, Columbus, Ohio.
Oklahoma Agricultural and Mech. Col.....Oct. 13, '11	G. E. Davis	W. C. Lane, Oklahoma A. and M. College, Stillwater, Okla.
Oklahoma, Univ. of,....Oct. 11, '12	H. M. Richards	R. E. Heffner, University of Oklahoma, Norman, Okla.
Oregon Agr. Col.....Mar. 24, '08	J. A. Hooper	L. Happold, Oregon Agri. College, Corvallis, Ore.
Penn. State College....Dec. 20, '02	G. Geracimos	August Heine, State College, Pa.
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Rose Polytechnic Inst...Nov. 10, '11	H. E. Smock	Sam P. Stone, 1012 North 8th Street, Terre Haute, Ind.
Rhode Island State Col.Mar. 14, '13	A. W. Thayer	Carl A. Burclich, Rhode Island State College, Kingston, R. I.
Stanford Univ.....Dec. 13, '07	H. W. Lewis	A. L. Morgan, Stanford University, Cal.
Syracuse Univ.....Feb. 24, '05	W. P. Graham	R. A. Porter, Syracuse University, Syracuse, N. Y.
Texas, Univ. of.....Feb. 14, '08	J. M. Bryant	J. A. Correll, Univ. of Texas, Austin, Tex.
Throop College of Technology.....Oct. 14, '10	J. Paul Youtz	Clark E. Baker, Throop Dormitory, Throop College of Technology, Pasadena, Cal.
Virginia Polytechnic Institute.....Jan. 8, '15	John D. Hindle	E. S. Smithson, Virginia Polytechnic Institute, Blacksburg, Va.
Virginia, Univ. of.....Feb. 9, '12	W. S. Rodman	J. H. Peebles, University, Va.
Wash, State Col. of.....Dec. 13, '07	C. H. Worthen	C. J. Melrose, State Col. of Wash., Pullman, Wash.
Washington Univ.....Feb. 6, '04	Charles A. Lieber	R. W. Macdonald, Washington University, St. Louis, Mo.
Washington, Univ. of...Dec. 13, '12	A. Kalin	J. R. Himmelsbach, 4629 21st Avenue, Seattle, Wash.
West Virginia Univ.....Nov. 13, '14	O. P. Joliffe	D. F. Cronin, 52 University Driveway Morgantown, W. Va.
Worcester Poly. Inst....Mar. 25, '04	C. W. Kennedy	J. A. Blair, Worcester Polytechnic Institute Worcester, Mass.
Yale University.....Oct. 13, '11	A. W. Cahoon	J. P. Allen, Sheffield Scientific School, New Haven, Conn.

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CHARACTERISTICS OF ADMITTANCE TYPE OF WAVE FORM STANDARD

BY FREDERICK BEDELL

Abstract of Paper

It is generally agreed that a sine wave of electromotive force at generator terminals and on transmission lines is best. A sine wave is now specified as standard by the Standardization Rules of the Institute, but the present methods for prescribing allowable limits and for determining how near an actual wave is to a true sine wave are very unsatisfactory. The Standards Committee, through a sub-committee, is studying the subject in order to ascertain whether a standard can be specified that will be more suitable in its characteristics and more practical in its application. As a contribution to this study, the characteristics of a certain type of standard are here set forth.

It is hoped that various points of view and much information may be brought out in discussion, which may be on the general subject and not limited to the particular phase discussed in the paper.

Introduction

ALTHOUGH in certain respects a departure from a sine wave of electromotive force at generator terminals or on a transmission line may not be objectionable, it has been found that in most respects such a departure is objectionable to a very high degree; the sine wave is, therefore, the generally recognized standard or ideal that all desire to see approached more and more closely as the art of electrical engineering progresses. The troubles that are caused by a departure from a sine wave depend to a considerable extent upon the frequency of the harmonic or harmonics which are present in the wave in addition to the pure sine wave of fundamental frequency. For example, harmonics of a certain more-or-less low range of frequencies cause trouble in the parallel operation of machinery, while harmonics of a somewhat higher range cause trouble by inductive interference with neighboring telephone circuits. In penalizing therefore, a departure from a sine wave, it becomes necessary either to penalize all harmonics equally, or to endeavor to make the penalty fit the crime and to prescribe different penalties to

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the various harmonics, which are present in addition to the fundamental, according to their frequencies.

The present Standardization Rules of the Institute, after stating that the sine wave shall be considered standard, specify the manner (Rule 406) by which the so called "deviation" from a sine wave shall be measured. This measure of deviation has been found generally unsatisfactory, not only because it involves expensive special apparatus (commonly an oscillograph) and the services of a man expert in such work, but also because even in the hands of an expert the numerical results are not directly obtainable, being found only, after a kind of cut-and-try or juggling process.

On account of these objections to "deviation" as a practical measure of wave distortion, there was introduced Rule 17*, which defines distortion factor without specifying the numerical value that will be allowed. It was doubtless felt that experience was needed before specifying such a numerical value; but experience has shown objections to a distortion factor as defined in Rule 17, as will be pointed out later. Meanwhile the objecttionable "deviation" rule, which all hope may soon be superseded, still persists.

The question of a standard for wave shape has been discussed† before the Institute on several occasions, and during the past year has been the subject of study of a sub-committee‡ of the Standards Committee. This paper describes certain work done in connection with the work of this sub-committee. It is not intended to be complete, nor to present conclusions, nor to commit the members of the committee in any way. Its object is to bring the matter to the attention of those interested, with a view to obtaining, through discussion or correspondence, different points of view and, so far as possible, to ascertain all the facts bearing on the matter. It is felt that to attempt to

*Rule 17. The Distortion Factor of a Wave. The ratio of the r.m.s. value of the first derivative of the wave with respect to time, to the r.m.s. value of the first derivative of the equivalent sine wave.

†A *Proposed Wave Shape Standard*, by C. M. Davis, TRANS. A. I. E. E., p. 775, Vol. XXXII, 1913; discussion, pp. 831-845. Three papers on *Irregular Wave Forms*, by F. Bedell and others, presented at Deer Park, 1915, PROC, A. I. E. E., pp. 1051-1086, June 1915; discussion, pp. 3087-3116, Dec. 1915.

‡ Messrs. L. W. Chubb, F. M. Farmer, H. S. Osborne, L. T. Robinson and F. Bedell, Chairman. Aid in the preparation of this paper, and in experiments not here reported, has been obtained from Messrs. A. Bailey, R. Bown, G. E. Grantham, W. G. Mallory and P. T. Weeks.

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standardize wave form with our present knowledge would be premature. There are so many sides to the question, and the interests involved are so diverse, that it is only through wide spread interest and discussion that all the facts and all the aspects of the case can be brought out. The scope of this paper is limited to the characteristics of a certain type of standard but the discussion may be more general.

Admittance Standards

Of the various factors that have been discussed before the Institute for defining the distortion of an alternating wave, the differential distortion factor, (which is the distortion factor of Rule 17, as given above) meets the requirements of a commercial standard perhaps better than any other.

For practical purposes this factor can be defined in terms of the admittance of a condenser as follows:

(*Condenser Admittance Standard.*) The distortion factor of an e.m.f. wave is the ratio of the admittance of a condenser supplied with that wave at its terminals to the admittance of the same condenser when supplied at its terminals with a sine e.m.f. of the fundamental frequency.

The objections to the condenser standard are three-fold: *First*, the wave form of the alternator under test may in some cases become distorted by the condenser used in making the test on account of resonance between the condenser and the inductance of the armature. (This resonance would be for some particular harmonic component of the alternator wave and this component would be unduly magnified so as to distort the e.m.f. form.) *Second*, the penalizing of lower harmonics is too little and of higher harmonics is too great. *Third*, for accuracy the condenser circuit must contain capacity only; hence any resistance or inductance of the ammeter used to measure condenser current introduces error.

These objections, however, can all be eliminated, if certain modifications are made in the definition of the standard and in the method of test; in this way a more practical and a more desirable working standard can be obtained. There are several ways in which these modifications can be made, leading to several possible wave form standards that will now be discussed.

As is well known the admittance of *any* circuit, or combination of circuits, containing inductance or capacity varies with the wave form of impressed voltage and with the fundamental frequency, so that, for a given fundamental frequency, the ad-

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mittance of a specified circuit is an indication of the wave form of voltage impressed at its terminals and may be taken as a measure of wave distortion.

A general definition of distortion factor, in terms of the admittance of some standard circuit, is, accordingly, as follows:

(*General Admittance Standard.*) The distortion factor of an e.m.f. wave is the ratio of the admittance of a specified standard circuit supplied with that wave at its terminals to the admittance of the same circuit when supplied at its terminals with a sine e.m.f. of the fundamental frequency.

Special cases arise according to the standard circuit specified. A condenser standard (giving the differential distortion factor, δ) and an inductance standard (giving the integral* distortion factor, σ) are seen to be special cases.

Any one of a limitless number of possible circuits might be specified as a standard, and each would give a distortion factor with certain characteristics of its own, as in the particular cases of δ and σ.

Circuits that might be taken as standard can be classified under two heads:

I. *Simple Standard Circuit*, in which resistance, inductance and capacity (or any one or two of them) are arranged in series and are given specified relations or values.

II. *Composite Standard Circuit*, in which the component parts are arranged in other than simple series arrangement.

A simple standard has the obvious advantages of simplicity; it is possible for the testing engineer to check up the standard or to duplicate it with apparatus commonly available. The significance of the standard and the results obtained can be readily grasped and the standard has, to a certain extent at least, a rational rather than an arbitrary basis. A composite standard, on the other hand, has the advantage that it offers a greater range of possibilities in the weighting of harmonics of different frequencies.

A simple standard itself offers great range in the weighting of harmonics, as will be brought out later, but, if no one of these possible weightings comes sufficiently near to the requirements of the case, it may be preferable to abandon the advantages of simplicity and to adopt a composite standard, provided that one is found that is so distinctly superior in its weighting as to make its adoption worth while.

*See Deer Park papers, *loc. cit.*

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A standard circuit consisting of resistance only would be impossible, for the admittance of such a circuit does not vary with wave form. A standard consisting of an inductance only would be impracticable (even were it desirable), for the admittance on any commercial wave would differ so little* from the admittance on a sine wave that the difference could scarcely be determined. For the same reason, a circuit consisting of R and L, combined, would be impracticable. Furthermore, a circuit consisting of L and C with no resistance (were this possible) would be unsuitable as a standard, for it would prohibit absolutely the existence in an alternator of an harmonic of a particular frequency; for acceptance of an alternator, the allowable value for the harmonic of the frequency at which L and C were in resonance would be zero, as seen later in connection with the curve marked "$R = 0$" in Fig. 2.

This leaves as possible the condenser standard, the $R\ C$ standard (which is the condenser standard with some resistance added in series) and the $R\ L\ C$ standard (which is the condenser standard with some resistance and inductance added in series). In all these cases the condenser is the predominant element, that is there would be but a small difference between condenser voltage and line voltage.

The condenser standard, without resistance, gives a chance for error in measurement (due to resonance between the condenser and armature inductance) as already pointed out. This error, however, may be reduced and practically eliminated by the introduction of resistance. We have, then, to choose between the $R\ C$ standard and the $R\ L\ C$ standard, and the choice between these two should be made after comparing the characteristics of each. It is to be noted that the presence of R and of C is essential; whereas the inductance† is not necessary, being added or not according to the characteristics that may be found desirable.

The accompanying curves show the characteristics for various standard circuits. The ordinates for each curve show the relative amplitudes that are allowed by the various standards for

*This difference is only a fraction of one per cent; thus, if the admittance of an inductive circuit on a sine wave is unity, it is 0.9952 on a wave having a fifth harmonic of ten per cent in addition to the fundamental.

†Inasmuch as the RC standard should be free from inductance, a small error is introduced by inductance in the ammeter; with the RLC standard this error may be avoided by including the inductance of the ammeter as part of the inductance of the standard circuit.

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harmonics of different frequencies, it being assumed in all cases that no more than one harmonic is present. The mathematical relations on which these curves are based are given in Appendix I.

As a basis for comparison, a curve for the condenser standard is shown by the dotted curve in each figure. The scale of ordinates is relative, the absolute values depending upon the specified value for the distortion factor. Thus, for the dotted curves, a distortion factor 1.12 allows a fifth harmonic equal to 10 per cent, of the fundamental, a seventh harmonic equal to about 7½ per cent., etc., the allowable amplitude decreasing* with the order of the harmonic. The fifth harmonic is marked for con-

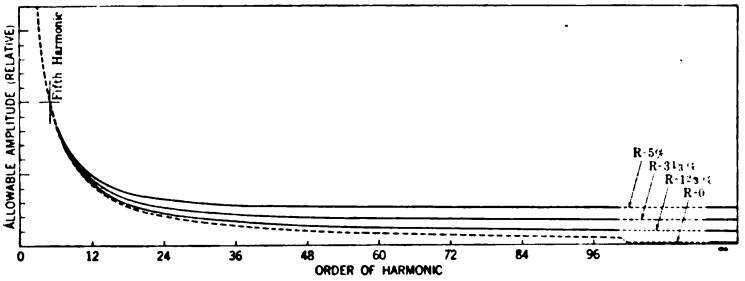

FIG. 1. *RC* standard, resistance being 1 2/3 per cent, 3 1/3 per cent and 5 per cent of reactance of condenser at fundamental frequency. The curves approach, $E_\infty = 5\,E_5\,\frac{R}{X_1}$ (approx.) at infinite frequency. Dotted curve is condenser standard.

venient reference. The value of the fifth harmonic, E_5, for different values of distortion factor, δ, are as follows:

E_5	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12
δ	1.02	1.03	1.045	1.06	1.08	1.10	1.12	1.145	1.17

The scale for the curves is thus determined in terms of distortion factor.

In Fig. 1, the solid curves show the characteristics of the *R C* standard for three different values of *R*, namely, $1\frac{2}{3}$, $3\frac{1}{3}$

*The amplitude varies (approximately) inversely as the order of the harmonic. If k is the order of the harmonic,

$\delta = (1 + k^2 E_k^2)^{\frac{1}{2}} \div (1 + E_k^2)^{\frac{1}{2}}$, as derived in Appendix I. The denominator $(1+E_k^2)^{\frac{1}{2}}$ differs from unity by less than half of one per cent, if E_k is not over 0.10. Substituting unity for the denominator, we have then, with an error of less than half of one per cent,

$\delta = (1 + k^2 E_k^2)^{\frac{1}{2}}$, or $E_k = (\delta^2 - 1)^{\frac{1}{2}} \div k$. For constant δ, E_k accordingly varies inversely as k, the dotted curve being an hyperbola.

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and 5 per cent of condenser reactance at fundamental frequency. These curves approach the limiting minimum value,

$$E_\infty = 5\ E_5\ \frac{R}{X_1},\ \text{approximately.}$$

The RC standard is practically free from the objections given for the condenser standard and it is readily assembled from apparatus commonly at hand. In this respect it is superior to the $R\ L\ C$ standard and, from the standpoint of practicability,* is the most satisfactory working admittance standard. Whether its characteristics are more or less desirable than those of the $R\ L\ C$ standard is a question to be determined; these latter characteristics will now be discussed.

The current flowing through an $R\ L\ C$ circuit at constant voltage increases with frequency until resonant frequency is reached and then decreases, as is discussed in various text books.† In the case of a distorted wave, the current produced by a particular harmonic varies in a like manner, a fact that has been made use‡ of in the determination of the amplitudes of the harmonics to which distortion is due. In the use of such an $R\ L\ C$ circuit as a standard, it is not necessary, however, to go so far as to determine the numerical values of the harmonics that may be present, but merely to make sure that the harmonics do not exceed certain specified values.

The curves in Fig. 2 show the characteristics for an $R\ L\ C$ standard and correspond to the curves shown in Fig. 1 with the addition of a certain inductance, so that L and C are resonant at a particular frequency, in this case 1500 cycles. Except for the inductance, the circuits for the curves in Figs. 1 and 2 are identical. It is seen that, in Fig. 2, the curves come to a definite minimum $\left(\text{approximately } 5\ E_5 \frac{R}{X_1}\right)$ at the resonant frequency instead of at infinite frequency, as in Fig. 1; this min-

*With the possible exception of the effect produced by ammeter inductance.

†See, for example, Fig. 32, "Alternating Currents" by Bedell and Crehore, 1892.

‡See "Analysis of E.M.F. Waves," by P. G. Agnew, *Bul. Bureau of Standards*, p. 95, Vol. VI., 1909, where the use of a series RLC circuit is described; for another arrangement, see articles by M. I. Pupin, *Am. Journ. Sc.*, pp. 379, 473, 1894. Resonant circuits have also been used to determine harmonic currents that are present in addition to direct current in trolley circuits.

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imum value is determined by and is directly proportional* to the resistance.

It will be seen that by selecting the values to be specified for distortion factor, and for R and L in the standard circuit, the characteristics of the R L C standard can be adjusted to a wide range of conditions. The minimum of the curve, which is the point of maximum penalty, has its position (*i.e.*, the fre-

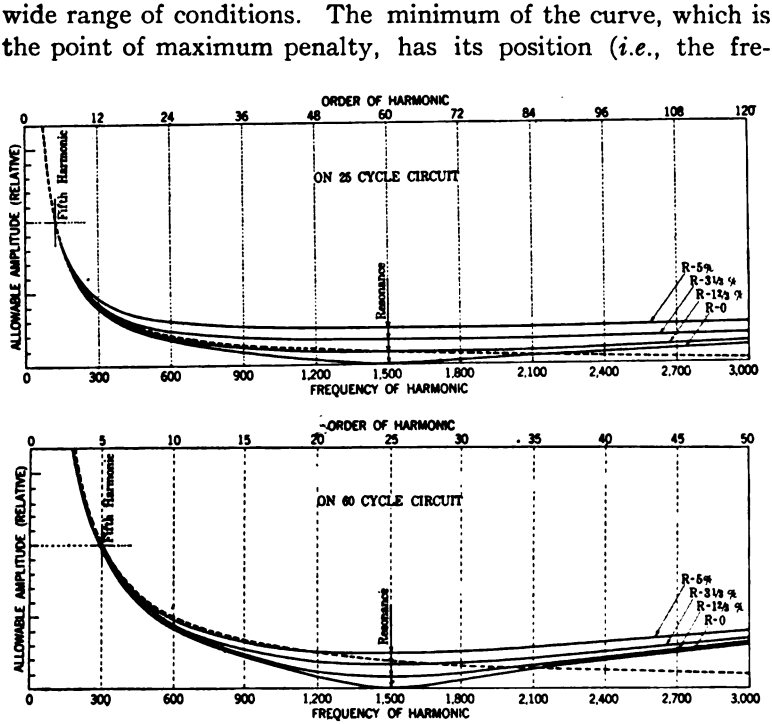

FIG. 2. *RLC* standard; resonance at 1500 cycles. Resistance is 0, 1 2/3 per cent, 3 1/3 per cent and 5 per cent of reactance of condenser at fundamental frequency. E at resonance $= 5 E_1 \frac{R}{X_1}$ approx. (On 25-cycle circuit, R is 1, 2 and 3 times reactance of condenser at resonant frequency. On 60-cycle circuit, R is 0.41, 0.83 and 1.25 times reactance of condenser at resonant frequency.) Dotted curve is condenser standard.

quency at which it occurs) determined by L; its relative value determined by R. The absolute value of the scale, for the whole, curve, is determined by the specified distortion factor.

It will be noted that no changes in the values of R L or C affect materially any of the curves for the lower harmonics,

*This is very close to a true proportionality for all practical cases; the departure from proportionality only occurs when the amplitude of the harmonic is much more than is generally found in practise.

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the allowable values for the lower harmonics being determined solely by the specified value for distortion factor. For the lower harmonics, the dotted curve for the condenser standard is seen to coincide practically with the solid curves of the *R C* and the *R C L* standards. It is thus seen that the constants of the circuit have a material effect only on the values of harmonics of the middle and higher ranges.

Fig. 2 shows the effect of varying *R* when *L* is constant.

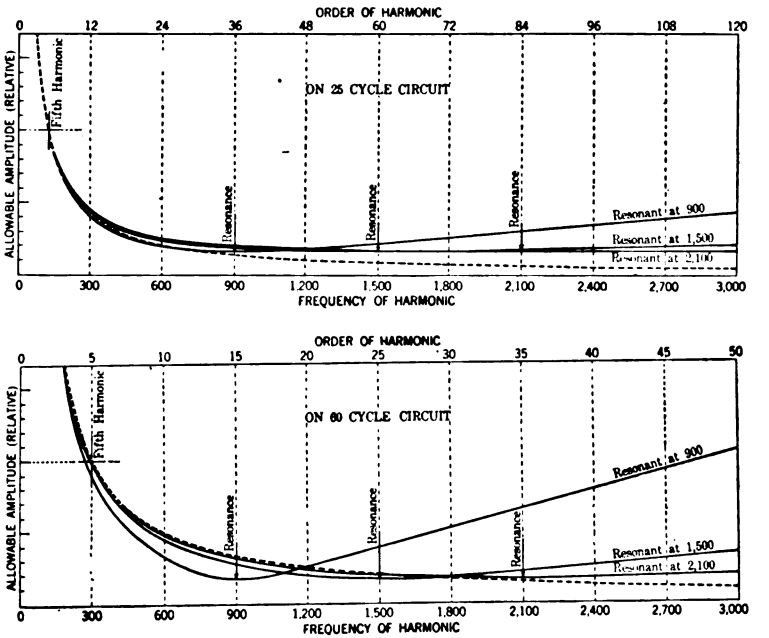

FIG. 3. *RLC* standard; resonance at 900, 1500 and 2100 cycles. Resistance is 3 1/3 per cent of the reactance of condenser at fundamental frequency. Dotted curve is condenser standard.

(It is understood that these values are not absolute but are relative to the value of *C*.) The intersection of the dotted curve with one of the solid curves at resonance is due to the fact that in this case the resistance had a value equal to the reactance of the condenser at resonance, a relation discussed further in connection with Fig. 4.

Fig. 3 shows the effect of varying *L* when *R* is constant. Three values are taken for *L* giving resonance at frequencies of 900, 1500 and 2100. A rapid rise in the curve after the minimum

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is reached is objectionable in a standard, and this is seen to be the more marked the lower the resonant frequency.

In Figs. 2 and 3, the value of R is specified in terms of the reactance of the condenser at fundamental frequency, and accordingly is different for 25- and 60-cycles circuit. As a result, the ordinates of the 25-cycle and 60-cycle curves are equal at resonant frequency; the amplitude of harmonic allowed is thus constant at this absolute frequency, irrespective of the order of the harmonic with respect to fundamental frequency.

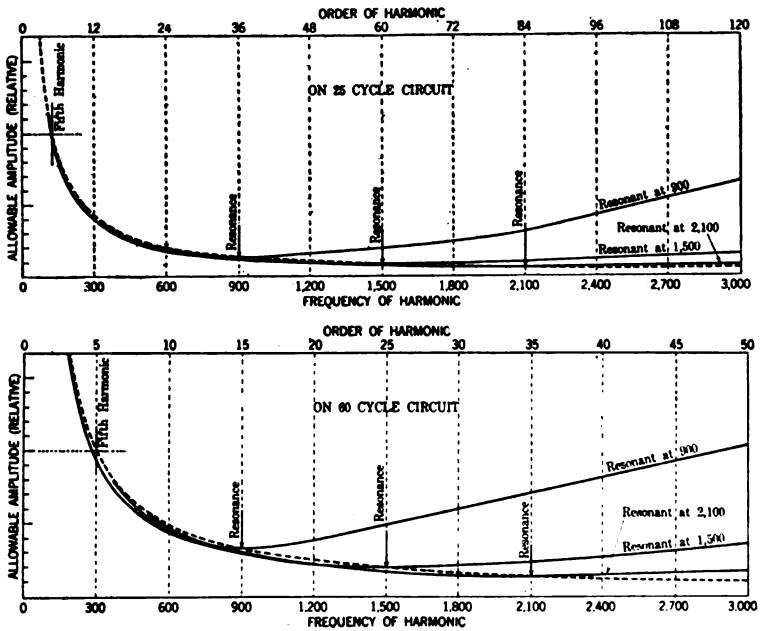

FIG. 4. *RLC* standard; resonance at 900, 1500 and 2100 cycles. Resistance is equal to reactance of condenser at resonant frequency, irrespective of fundamental frequency. Dotted curve is condenser standard.

Fig. 4 shows the characteristics of the *RLC* standard when R is constant, irrespective of the frequency of the circuit, R being equal to the reactance of the condenser at resonant frequency. Curves are drawn for three resonant frequencies. It is seen that in each case, in Fig. 4, the curves closely follow the dotted curve of the condenser standard up to the resonant point. Up to this point, each curve lies just below the curve for the condenser standard, thus imposing a slightly greater penalty on harmonics through this range.

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Although it is more logical for the value of R to depend upon fundamental frequency, there would be an obvious practical advantage in having R constant, irrespective of fundamental frequency, for all circuits. If R were made equal to the condenser reactance at resonant frequency, there would be a further advantage that the resonant distortion factors thus defined differ little in numerical value from the present (differential) distortion factor, the solid and dotted characteristic curves, in Fig. 4, following each other closely up to the point of resonance, where they intersect; resonant distortion factor is then a modification of the distortion factor of the condenser standard. But such a factor would be open to the objection already raised to the condenser standard, namely, that the lower harmonics are not penalized enough or the higher harmonics are penalized too

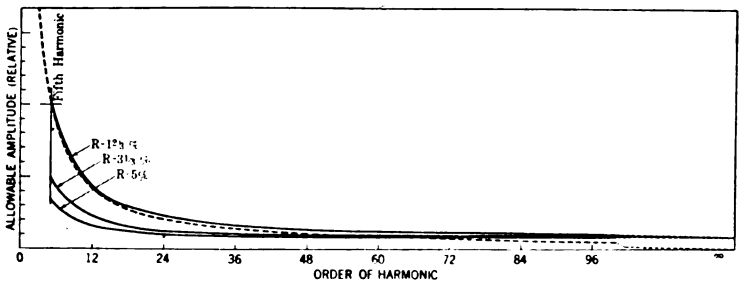

FIG. 5. RC standard; the same as Fig. 1 with scale changed so that curves coincide at infinity. Resistance is 1 2/3 per cent, 3 1/3 per cent and 5 per cent of reactance of condenser at fundamental frequency.

much. By increasing the value of R, the solid curves in Fig. 4 would be raised in the region of resonance in the same manner as in Fig. 2.

It is to be kept in mind that any change in R affects only *relative* values of the allowable harmonics at different frequencies, provided the appropriate numerical value is assigned to the distortion factor.

A comparison of Figs 5 and 6 with Figs 1 and 2 may make this clearer. Each curve in Fig. 1 is drawn for the same value of distortion factor, this causes the curves to practically coincide at low frequencies (irrespective of the value of R) and to diverge at high frequencies. The curves of Fig. 1 are redrawn in Fig. 5, each for a different value of distortion factor, so that they coincide at infinite frequency and diverge at low frequencies. In a like manner, the curves of Fig. 2 are redrawn in Fig. 6, with

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different values of distortion factor, so as to coincide at resonant frequency.

From the foregoing study it will be seen that an increase in R decreases the penalizing of the high harmonics *relative* to the low (or increases the penalizing of the low harmonics relative to the high), the absolute value of either high or low being not necessarily affected.

It should be noted that an increase in resistance tends to decrease the sensitiveness of measurement; thus, in Fig. 5 or 6, the distortion factor might be changed from, say, 1.17, with the smaller resistances, to about 1.05 and 1.02, respectively with the larger resistances.

If a standard of the admittance type is deemed desirable, there are many points to be decided before the exact specification

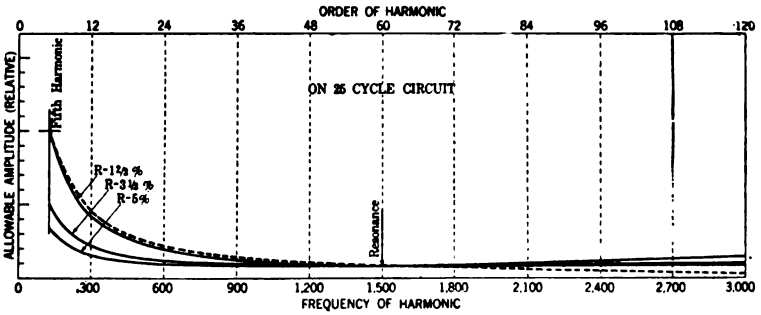

FIG. 6. *RLC* standard; the same as Fig. 2 with scale changed so that curves coincide at resonant frequency. Resistance is 1 2/3 per cent, 3 1/3 per cent and 5 per cent of reactance of condenser at fundamental frequency, or 100 per cent, 200 per cent and 300 per cent of reactance of condenser at resonant frequency.

of the standard can be determined. Some of these points are as follows:—

1. Shall the standard circuit be a simple circuit, as described in this paper, or a composite circuit?

2. If a simple circuit is to be adopted, shall this circuit contain an inductance and, if so, how much; or, in other words, what shall be the resonant frequency?

3. How much resistance shall the standard contain; should this resistance be different for circuits of different frequencies, or should it be the same for all frequencies?

4. What numercial value of the factor thus specified should be allowed in acceptance of alternators?

5. What details and what load conditions conducting tests should be specified?

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APPENDIX I

Formulas for Distortion Factors

An irregular voltage wave, composed of a fundamental E_1 and harmonics E_3, E_5, E_7, etc., has a r.m.s. value

$$E = (E_1^2 + E_3^2 + E_5^2 + \ldots)^{1/2}$$

If Y_1, Y_3, Y_5, etc., are the admittances of the standard circuit for the fundamental and for the several harmonics, respectively, the current taken by the standard circuit when subjected to the irregular voltage E, is

$$I = (E_1^2\, Y_1^2 + E_3^2\, Y_3^2 + E_5^2\, Y_5^2 + \ldots)^{1/2}.$$

The admittance of the standard circuit on the irregular wave is I/E; its admittance on a sine wave is Y_1. The former divided by the latter gives

$$\text{Distortion factor (general)} = \frac{\frac{I}{E}}{Y_1} = \frac{\sqrt{1 + \left(\frac{Y_3 E_3}{Y_1 E_1}\right)^2 + \left(\frac{Y_5 E_5}{Y_1 E_1}\right)^2 + \ldots}}{\sqrt{1 + \left(\frac{E_3}{E_1}\right)^2 + \left(\frac{E_5}{E_1}\right)^2 + \ldots}}$$

$$= \frac{\sqrt{1 + \left(\frac{Y_3}{Y_1} E_3\right)^2 + \left(\frac{Y_4}{Y_5} E_5\right)^2 \ldots}}{\sqrt{1 + E_3^2 + E_5^2 + \ldots}}$$

In this last equation, E_1 has been taken as unity.

When only one harmonic of order k is present

$$\text{Distortion factor} = \frac{\sqrt{1 + \left(\frac{Y_k}{Y_1} E_k\right)^2}}{\sqrt{1 + E_k^2}}$$

All the curves in this paper are determined by this equation, by giving a constant value to distortion factor and determining E_k for different values of k.

The preceding equations are general and apply to any standard circuit. For the particular case of the condenser standard, $Y_3/Y_1 = 3$, $Y_5/Y_1 = 5$, etc.; hence

$$\delta = \frac{\sqrt{1 + (3\,E_3)^2 + (5\,E_5^2) + \ldots}}{\sqrt{1 + E_3^2 + E_5^2 + \ldots}}$$

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When only one harmonic is present,

$$\delta = \frac{\sqrt{1 + (k E_k)^2}}{\sqrt{1 + E_k^2}}$$

This equation may be used in determining the dotted curves in Fig. 1 to 4.

APPENDIX II

Measurements

It has not been the object of this paper to discuss at length experimental details, nor to bring up various questions relating thereto. A brief statement concerning test methods will, however, not be out of place.

The admittance of a standard circuit, when supplied at its terminals with the voltage under test, is readily determined by ammeter and voltmeter readings. Unless an electrostatic voltmeter is used, the ammeter should be included as part of the standard circuit, the resistance and inductance of the instrument (unless negligible) being included in the specified values of R and L for the standard.

The admittance of the standard circuit on sine wave voltage may be determined either by calculation or by voltmeter and ammeter readings when sine voltage is impressed at the terminals of the standard.

In the former case, it is necessary to know accurately the absolute values of $R\,L\,C$ and frequency, and also the absolute values of the current and voltage in the determination of admittance on the irregular wave. Great care is therefore necessary to insure dependable results.

In the latter case the value of I/E on the irregular wave, divided by I/E on the sine wave gives the distortion factor. It is seen that in this case only relative values are necessary, as the result is a ratio; fairly accurate results can be obtained even with rather crude instruments, provided, of course, that the readings on the irregular wave and the sine wave are both taken with the same ammeter and voltmeter.

A sine wave sufficiently pure for the purpose can be derived from the irregular voltage wave by augmenting the fundamental and choking out the harmonics. One way* for accomplishing this that has been found satisfactory is to place in parallel with the standard circuit a condenser C' having a capacity prefer-

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ably much larger than the capacity of the condenser in the standard (say five times as large) and to place a non-ferric inductance L' in series with the combination of C' and the standard circuit in parallel. The inductive reactance of L' at fundamental frequency should be greater (say at least 25 per cent greater†) than the capacity reactance of C' at fundamental frequency. With suitable switches, the ammeter and voltmeter readings giving the admittance first on the irregular wave and then on the sine wave are readily taken; the ratio gives the distortion factor.

The numerical values of distortion factor with the RC or RLC standard will differ but little from the value of differential distortion factor δ, particularly when R and L are specified with a view to making this difference small. To do this may be worth while, in view of the fact that δ is a constant of definite theoretical significance and of use in certain calculations.‡

It may be pointed out that the measurement of $\delta\sigma$ by the split dynamometer method, referred to in one of the Deer Park papers, is also practically a measurement of δ, inasmuch as the value of σ is so nearly unity,—more than 0.995 in most cases. (For this reason certain objections to the condenser or δ standard hold as well for the $\delta\sigma$ standard.) The dynamometer reading varies as the product of the current in the two windings. The current in one winding is derived through a condenser reactance and is proportional to $\delta/C\omega$; the current in the other winding is derived through an inductive reactance and is proportional to $L\omega$. The product is proportional to $\delta\sigma$ and is independent of frequency. The reading of the instrument is, however, dependant upon voltage. By substituting suitable resistances for the reactances, the reading of the instrument with reactances in circuit divided by the reading with resistances in circuit gives the value of $\delta\sigma$ irrespective of voltage or fre-

*This is essentially the method by which a sine wave has been obtained for the Ryan Cathode Ray Oscillograph; see TRANSACTIONS, A. I. E. E., p. 539, Vol. XXII, 1903.

The Davis method (*loc. cit.*) is a particular case in which $C = 0$. The presence of C' reduces the size of L' and gives a resultant sine wave with greater accuracy when the standard contains R and L as well as C.

†Strictly speaking, it must be greater than the joint reactance of C' and C in parallel. It should be enough greater to make *sure* that it is greater and to avoid instability of readings that may occur when inductive reactance and capacity reactance are nearly equal.

‡See Mizushi paper, Deer Park, *Loc. cit.*

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quency. Variations of voltage and frequency even as much as 100 per cent have been found tolerable.

The dynamometer wave-form meter has been made more sensitive by a differential arrangement, two dynamometers being mounted on one moving system, the two coils of one dynamometer deriving current through inductive and condenser reactances, respectively; the two coils of the other, through resistances. The simpler single split-dynamometer has, however, been found by the writer to be sufficiently sensitive.

Theoretically the split dynamometer gives true values of $\delta\sigma$ only when the two reactances have zero resistance, a condition that can be approached but not exactly obtained. By putting resistance or resistance and inductance in series with the condenser, it might be possible to make the readings of the instrument approximate the distortion factor of the RC or RLC standard, but these possibilities have not been investigated.

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To be presented at the Pacific Coast Convention the American Institute of Electrical Engineers, Seattle, Wash., September 5, 1916

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(*Subject to final revision for the Transactions.*)

THE HIGH-VOLTAGE POTENTIOMETER

BY HARRIS J. RYAN

ABSTRACT OF PAPER

The author describes a high voltage potentiometer which may be made at reasonable expense consisting of a water resistance potential distributor and a sparking probe potential difference detector. The water resistance consists of a column of water moving slowly through an ample length of garden hose, and tapping in points through which to connect the probe are provided by breaking the hose at regular intervals and connecting it with any of the plain metal connectors found on the market as "hose menders." The results of an integrity trial are charted in Fig. 2. The device is intended for investigations in which the results are not required to be known within 2 or 3 per cent of their actual value.

THE potentimoter method for the determination of altering potentials or for the measurement of alternating voltage duties requires: 1. A *distributor* of alternating potential, identical in phase and wave form with the alternating potential to be determined. 2. A satisfactory potential difference *detector* to determine when the known potential from the distributor matches the unknown potential to be measured. For a high-voltage potentiometer at reasonable expense the following types are feasible:

A source of synchronous variable voltage that matches the voltage to be measured in phase and wave form; requires a phase-shifting transformer and an induction regulator or a suitable multiple-tap transformer.

A condenser connected to the high-voltage source having a variable potential feature as follows: A fluid dielectric and a potential tapping plate electrode that may be moved to any position between the main electrodes of the condenser, or a series of electrode potential plates mounted in the dielectric between the main electrodes at uniform intervals.

A chain of equal water resistances connected across the same high-voltage source as the test specimen from which any required potential may be tapped.

Manuscript of this paper was received July 3, 1916.

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There are two types of detector available:

The sparking probe.

The Bennet small current oscillograph.*

In the sparking probe detector advantage is taken of the fact that a spark occurs at a pointed electrode when used to connect two condensers charged to different potentials. This is true even when the capacitances and differences of potentials are small. In the Bennet detector an oscillograph with suitable auxiliary equipment is used to observe the charging current taken by the insulator system under observation, and to note when the potential applied to a conductor is such that it may be brought in contact with a metal part of the insulator system without disturbing the normal value of such charging current.

The author has had experience in the development and use of these several potential distributors and the sparking probe detector. He has had no experience with the Bennet detector, though he is convinced, from his own experience, that such detector will yield reliable results. Of the several expedients specified it has been found that the water resistance distributor and the probe detector constitute a convenient and reliable high-voltage potentiometer that may be constructed of common materials with ordinarily skilled labor at small cost. A column of water moving slowly through an ample length of garden hose constitutes the resistance. The length of hose required for a given over-all voltage may vary considerably. The author has used *one foot* (30.4 cm.) of hose *per one thousand* maximum range effective *volts*. Tapping-in points from which to connect the cable leading to the probe are provided by breaking the hose at regular intervals and connecting it with any of the plain metal connectors found on the market as "hose menders". The illustration in Fig. 1 was taken from a photograph of one of these water column potential distributors. The hose is of the common *three-quarter-inch* (1.9 cm.) variety, 75 ft. (22.8 m.) long, in 50 sections of 18 in. (45.6 cm.) each. It is formed into a cylindrical helix of twelve and one half turns on a diameter so as to use four sections per turn and so as to make corresponding metal connectors line up in four columns on the surface of the helix-cylinder. The turns are spaced, insulated and held together by strain insulators and light galvanized steel strands

*Distributing Potential over a String of Insulators. By J. L. Brenneman and Harold M. Crothers. *Electrical World*, Vol. 64, Dec. 5, 1914. p. 1095.

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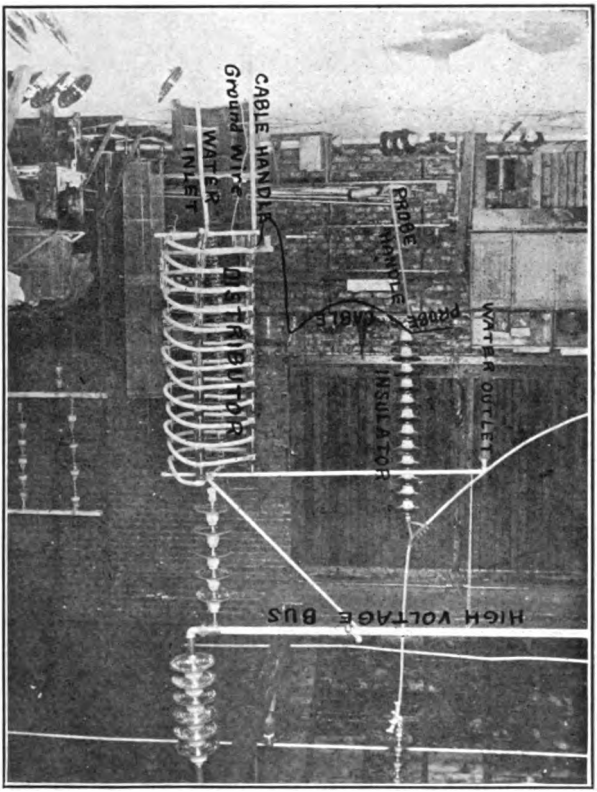

FIG. 1—HIGH VOLTAGE POTENTIOMETER [RYAN]

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located at the metal connectors. The hose starts at the bottom from one branch of a supporting cross formed of *three-quarter*-in. (1.9 cm.) galvanized iron pipe and a five-way fence-pipe fitting. It ends at the top in a branch of a duplicate pipe structure. The bottom end is attached to the water supply and grounded if this water connection is made through rubber or other non-conducting hose. The branch of the top cross is connected to one of the high-voltage source terminals and extended horizontally to a convenient distance, five ft. (1.5 m.), and terminated downward in a common sprinkler nozzle. The openings in the nozzle are large and numerous enough to permit ample exit of water without pressure. The water then falls away in drops, thus breaking the circuit that would otherwise be formed in parallel with the distributor circuit.

One of the four columns formed by the strain insulators is selected for mounting the tapping-in terminals of the conductors that lead through the interior of the helix to their corresponding metal hose connectors. These tap conductors are made of No. 10, B. & S. gage galvanized steel wire. To make probe connecting terminals at the outer ends of these tapping wires, such ends are formed into nearly complete rings finished with eyes and clamped with small bolts in proper order around the strain insulators. In an over-all sense this construction is strategic against corona formation.

Ordinarily 75 kilovolts will set up 50 milliamperes through this distributor. The amount of the current naturally depends upon the temperature of and the impurities in the water. Obviously variation in the value of the current through the distributor does not affect the integrity of the potentiometer results. It is only necessary in connection herewith that the current shall always be large compared with the charging current that passes from the probe cable to surrounding objects. The length of the cable used with this distributor is *ten* ft. (three m.) Its capacitance to earth does not exceed 0.000025 microfarads and the charging current liberated from it at 75 kilovolts to earth is, therefore, not more than *seven-tenths* of a milliampere.

The development and study of these various forms of high-voltage potentiometer was begun in March, 1912. Many integrity trials of them have been made. Some of the results thus obtained have been published.* The water resistance

*High Voltage Potentiometers *Jour. Electricity, Power, and Gas*, Vol. 34, April 10, 1915.

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distributor was developed during the present year and after the author was told by Mr. Faccioli that a resistance distributor had been found to give excellent results. Experience with the transformer and condenser types of distributor showed that the water resistance distributor must yield reliable results, consequently only one integrity trial of it has been made, and that with no particular care. In this trial the potentials of a light chain were determined when suspended in the electric field formed between two parallel lengths of pipe by 140 kilovolts. The chain was mounted at various distances from one of the conductors and its corresponding potentials were determined by the potentiometer and calculated from the known dimensions. The results are charted in Fig. 2. No great accuracy is claimed

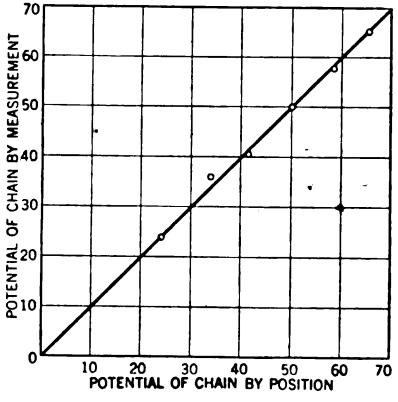

FIG. 2.

for the outfit. It is intended only for those studies in which the results are not required to be known within two or three per cent of their actual values.*

The potentiometer may be used to determine the potential of any outline or surface of an insulation system whereat or where-on a metal wire or sheet may be mounted and to which the potential probe can be applied. Such wire or sheet is called the insulator *potential electrode*. In general the capacitance of the insulator potential electrode is relatively small. The effect of the presence of the probe will, therefore, be such

*It should be noted that the results of the integrity trial charted in Fig. 2 embrace two classes of errors, only one of which is chargeable to the potentiometer, while structural deformities and defects in chain location measurements are responsible for the other.

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as to alter the potential of the electrode somewhat. The only result thereof is to widen the zone of potential through which the detector indicates an equally good balance. This effect occurs alike above and below the true potential of the insulator electrode and is eliminated by reading at the middle of the potential balance zone. The true balance must often fall between the potential taps as actually provided in the distributor. This is an additional cause that generally prevents a tap being found at which absolutely no probing spark is discernable in full darkness. For example in securing the results charted in Fig. 2 when the center of the chain was located seven in. (2.1 m.) from the surface of one of the high voltage conductors a faint but definite spark occurred between the probe point and chain at the 22 per cent tap and again at the 25 per cent tap; 23.5 per cent of the line voltage was, therefore, as the reading for the potential of the chain in this position. When the probe point was applied to the chain carrying potential tapped at 23 and 24 per cent of the line voltage, barely discernable sparks passed; they did not differ in recognizable degree showing that the true balance occurred midway between them.

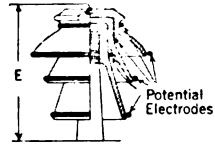

FIG. 3.

It is not thought necessary to discuss matters of this sort further. It is believed that anyone whose general training and experience have prepared them to take up work of the present character will have no difficulty in learning quickly from their own perceptions and efforts the correct procedure for this sort of potentiometer. Obviously two persons must work together to apply it. One handles the probe and the other handles the probe cable from tap to tap in the distributor until a potential balance is found. The probe and tap ends of the probe cable are each handled at the end of a suitable stick of clear quality wood, such as redwood, white pine or poplar, impregnated with paraffin as a precaution against the absorption of water. In work upon such insulation systems as a suspension type insulator the person or the operator should be as distant as possible and permit of the proper handling of the probe in order that the electric field about the insulator and therefore the voltage duties of its parts will not be disturbed. It is thought unnecessary to point out the many expedients that may be employed in locating and mounting insulator potential electrodes so as to explore the

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intensity of the electric fields in the air, oil or within the solid dielectrics of any system of insulation. These will promptly suggest themselves to anyone likely to have work of this sort on his hands to do.

In Fig. 3 the cross section of a pin type insulator is given showing the location of wire hoops to constitute insulator potential electrodes for the purpose of determining the voltage duty of the air about the insulator, over its surfaces and through its solid sections. It is obvious that these wire hoops must be located in equipotential surfaces. Their presence does not disturb the electric field nor the voltage duties of the insulator parts and of the surrounding air.

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To be presented at the 10th Annual Convention of the Association of Iron and Steel Electrical Engineers in joint session with the American Institute of Electrical Engineers, Chicago, Ill., September 18-22, 1916.

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(Subject to final revision for the Transactions.)

UNDERGROUND DISTRIBUTION SYSTEMS

BY G. J. NEWTON

ABSTRACT OF PAPER

The object of this paper is to show the importance of properly designing an underground distribution system for the district it serves and the particular service it is to supply. Simply placing the wires underground does not constitute an efficient system.

Underground distribution is the ultimate solution of the distribution problem that confronts every Electric Light and Power company operating in progressive towns and cities. The excessive cost of this class of construction, as compared with aerial construction, and the permanent nature of the system, warrant a careful study of the conditions and justifies a reasonable expense in the development of suitable plans for the system.

The financial success of an electrical undertaking depends on supplying efficient and reliable service in an economical manner, and in order to secure this result the distribution system must be carefully designed and properly installed.

The automatic substation, when perfected and adopted, will not only permit a great reduction in the number of ducts required and a lower first cost, but will provide more reliable service and bring underground distribution within the reach of many small companies where the cost of this class of service would not be warranted under the former conditions.

The suggestions offered in this paper are based on many years experience and are made with a sincere desire to aid those interested in this class of work, particularly in the design and installation of the first system in the smaller cities.

THE FOLLOWING facts and suggestions are based on many years experience with underground distribution systems, and are stated in the following article with the intention of showing the importance of careful and intelligent design as related, not only to the first cost, but to the economical operation and ultimate value of the completed system.

An inspection of many systems has made it evident to the writer that improper design is responsible for more faults than is poor construction, and it is with a sincere desire to aid others interested in this work, to avoid such mistakes in the future, that these suggestions are offered.

Manuscript of this paper was received April 7, 1916

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No two systems are entirely alike, and the conditions are different in every place; it is, therefore, impossible to formulate any definite rules that will apply under all conditions. The engineer must be guided by good judgment, based on experience, and a thorough study of the conditions in order to secure satisfactory results.

Owing to the increasing demand for electrical energy, and the serious objection to the unsightly and dangerous overhead wires and poles, underground systems of distribution have become a necessity in many places where the expense of this class of service would not have been considered warranted under former conditions.

Underground distribution is very expensive, as compared with overhead construction, and in many cases, particularly in the smaller cities, the first cost is of vital importance; a carefully worked out design is therefore necessary in order to derive the greatest benefit from the money expended. Many of the present systems have not been designed with the care, and attention to detail, that their importance deserves and frequently the cost of the system has been entirely out of proportion to its ultimate value.

The first installation of an underground system is made necessary by an order of the city authorities compelling the removal of poles and wires from certain sections of the city or by the desire of the operating company to improve the service and secure greater facilities in a district where the demand for light and power has reached a point that this class of service is warranted.

In either of the above cases, and in fact, practically in all cases in this country, underground systems are never installed until long after the district has been supplied by an overhead system. As a general rule, all overhead systems are the result of a series of extensions and changes, rather than the development of any systematic plan of distribution, and are seldom based on efficient or economical methods.

If it were possible to design and install an underground system at the start of an electrical undertaking the problem would be much simplified, as the station and consumers equipment could be selected, and the whole system designed for the most efficient results. Unfortunately the conditions are never so favorable, and the distribution engineer is confronted with many conditions over which he has no control, but must consider in making his plans.

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Distribution problems are, therefore, usually very complex and permit of several methods of being solved. It is only by a careful study of the conditions and foresight as to the future requirements of the system that a satisfactory, economical and efficient design can be developed.

The conditions under which underground cables and equipment operate are more severe than on overhead systems, and a thorough knowledge of these conditions is absolutely necessary, and must be kept in mind, in selecting cables and equipment and designing the conduit system for their installation. Overhead wires can be, and frequently are, operated far above their rated capacity, without any serious danger, but underground cables and equipment must be operated within certain definite limits in order to avoid serious damage, if not total destruction.

Economy of distribution is equally as important as economy in production, particularly at the present time, when practically all public utility companies are regulated, to a greater or less extent, by state or municipal commissions. First cost is not, therefore the only factor that should be considered, as economical operation and reliability of service are equally as important in the financial success and growth of the business.

Except in the large companies, there is probably no branch of the business that has been given less thought and study than underground work; in many cases the principal object evidently has been to get the wires out of sight at the least possible expense, with no attempt being made to improve the system of distribution and little or no regard for the future development of this class of service.

The operation of an underground system, when properly designed, installed, and maintained guarantees the most reliable and efficient service of any method of distribution ever employed; the financial benefit, directly due to this class of service is, in many cases, a proof of the wisdom of its installation.

While it is admitted that underground systems are expensive to install, still it must be remembered that a conduit system is a permanent structure, has little or no depreciation; on the contrary it will increase in value as the importance of the section it serves is developed. Considering the first cost, permanent nature of the undertaking, and importance of economical and reliable service, it is advisable to make a thorough study of the conditions and future requirements of the service on which to base a design of the proposed system.

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In designing an underground distribution system there is one important fact that must always be considered—the system should be designed to serve the entire district that can reasonably be expected to ever require this class of service. Such a design permits of a systematic scheme being developed for the whole district, uniform methods of construction, and standardization of equipment.

If this method is followed it is then possible to install any section, from time to time as the service demands, and each completed section will form a part of the whole general scheme and eventually develop into a system rather than a collection of more or less useful sections of conduit.

135 Washington Street. No. .....
William Henderson & Co. VOLTS 110 - 220

LIGHTING LOAD

SIZE			10	25	40	50	60	80	100				WATTS
LIGHTING				40		20	110						6600
SIGN			90						5				1400

APPLIANCES

10 Desk Fans	660
3 Irons	300
TOTAL LIGHTING LOAD	10960

POWER

2 - 5 HP 220 Volt 3 ϕ Motors	10000
1 - 10 HP 220 Volt 3 ϕ Motor	10000
TOTAL POWER LOAD	20 Kw.

L. SERVICE 105 ft. #4 - 3 Conductor.	TRANSFORMER 14 A
P. SERVICE 110 ft. #4 - 3 Conductor.	TRANSFORMER 14 A - B - C.

FIG. 1

It is not the object of this article to show each step in the design of any particular system but rather to point out certain important features to be kept in mind and offer suggestions as to the general method to be adopted; it is only by a thorough study of each case that the best methods can be determined.

The first step in designing an underground distribution system is to secure an accurate load record for each consumer in the proposed underground district. This record should be kept on cards similar to Fig. 1; where there is a large power load in the district it is advisable to make separate records for the lighting and power loads, using different colored cards for each record.

The card shown in Fig. 1 is simply a sample, and the best

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arrangement of the inventory on the cards will depend on the requirements of each particular system.

The reverse side of the cards can be used for showing the number and location of the transformer supplying the service lateral, consumers fuse box and other information connected with each consumers service.

These cards if properly corrected will form a permanent record of great value in making future changes and balancing the load on the distribution system.

The men securing the load record should be provided with paper pads printed the same as the cards and the permanent card record can be made in the office from these slips and the cards be kept clean and neat.

A careful inspection should be made of each building to determine the most suitable location for the new underground lateral in order to reduce the cost of changing the inside wiring as much as possible. Except in the case of very heavy loads or consumers where emergency service must be provided for, it is advisable to supply all of the consumers in a building from one lighting and one power lateral, this reduces the number of laterals, handholes, and fuse boxes and permits using the least amount of copper by taking advantage of the diversity of a group of consumers.

The lighting and power load can be plotted on one drawing as shown in Fig. 2 or the loads can be plotted on separate plans, the latter method is best as the plans for each system can then be kept separate.

The load maps for each system should show the total load, both in the underground district and outside of it, that is to be supplied by cables in the conduit system from the power house so that ample conduit space can be provided and the most suitable routes and sizes of feeders determined.

Having the lighting and power loads and a map showing the street light system, the next step is to determine the most suitable plan of distribution to be adopted, this may be called the critical point in the design of a distribution system, for on the decision depends not only the first cost of the installation but the reliable, efficient and economical operation of the distribution system.

There are two general schemes of distribution:

1. To supply the whole city from one power house.

2. Divide the city into districts and supply each from substations, or rather from the power house and substations.

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In many of the older systems the first method was used and a large number of ducts were installed, in one trench from the power house, to serve the whole city, or at least that portion that was to be supplied by underground eventually. This necessitated providing a large number of spare ducts, a large percentage of which remained idle for years and not infrequently resulted in too many ducts in some places and too few in others.

Not only was the first cost of such a system excessive but the manholes were almost invariably too small to accommodate the number of cables that could have been installed in all of the ducts had there ever been use for them. The most serious objection to this plan is that the losses due to the heating of so many cables in one conduit run are excessive and materially reduce the carrying capacity of the cables, particularly in cables occupying the inner ducts.

Another serious objection to this method is that a burn-out on one cable is practically certain to damage adjacent cables and cause interruption of service over a considerable area. Faults on underground systems usually affect more consumers than on an overhead system and require more time to repair, therefore, no system should be considered that does not permit being sectionalized and have reasonable emergency facilities provided for restoring service with the least possible delay.

The objections to the first plan, as stated above, preclude its adoption except in very small cities where the area to be served by underground distribution is limited, and the total number of ducts installed in one trench will not be excessive.

The second method of distribution, when properly designed, avoids all of the objectionable features of the first method and is particularly adapted to the modern practice of installing substations supplied by high-tension feeders, as each district is practically operated separate from the others and with suitable emergency feeders and switching equipment permits each district to assist the others in case of necessity.

The old saying "That you should not put all of your eggs in one basket" is particularly true if we change the words slightly—"You should not put all of your feeders in one trench or manhole" and the distribution engineer will be wise to keep this warning in mind as far as the requirements of the case will permit.

Reliable service and economical distribution are absolutely necessary for the financial success of every light and power company. Reliability depends on the following conditions:

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1. The best material, equipment and workmanship.

2. Proper selection of material and equipment for the service it is to supply.

3. Efficient protective apparatus, judiciously installed.

4. Sectionalizing apparatus properly located.

5. Continuity of supply, by feeders over different routes or an arrangement that will provide at least two sources of supply for the network.

6. Regular and systematic inspection of the distribution system by competent men.

7. Accurate plans and records of the distribution system so that changes, additions and extensions can be made to the best advantage with the least possibility of error.

Economical operation depends upon a reasonable first cost, in addition to all of the above conditions, and where a system is designed at first for a whole city (keeping in mind future substations) it is possible to reduce the number of ducts and manholes to a minimum, install sections as the business warrants and extend the ultimate cost over a considerable period.

Keeping the above facts in mind the actual design of an underground distribution system should be made on the following general plan. Assuming that the first underground installation is to supply a district similar to that shown in Fig. 2, and that later this district will be extended a block or two in each direction and supplied from the main station.

While it is admitted that it is not possible accurately to foretell where substations will be located in the future, still a study of the conditions will generally permit a reasonable assumption to be made and if separate conduit is to be installed later for high-tension feeders this part of the work does not enter into the first design except in a general way.

After making the load maps for the lighting and power systems and also a map showing the location of the street lights it is a good plan to first layout the street light circuits, for assuming that all wires in the district must be placed underground it is evident that conduit must be installed to reach every light.

The location of the street lights is determined by the city authorities and can seldom be altered enough to materially change the conduit arrangement, therefore, by designing this system first it will give a general idea of where the conduit *must* be installed and keeping this plan in mind it is frequently possible to arrange the secondary mains so as to utilize the same routes

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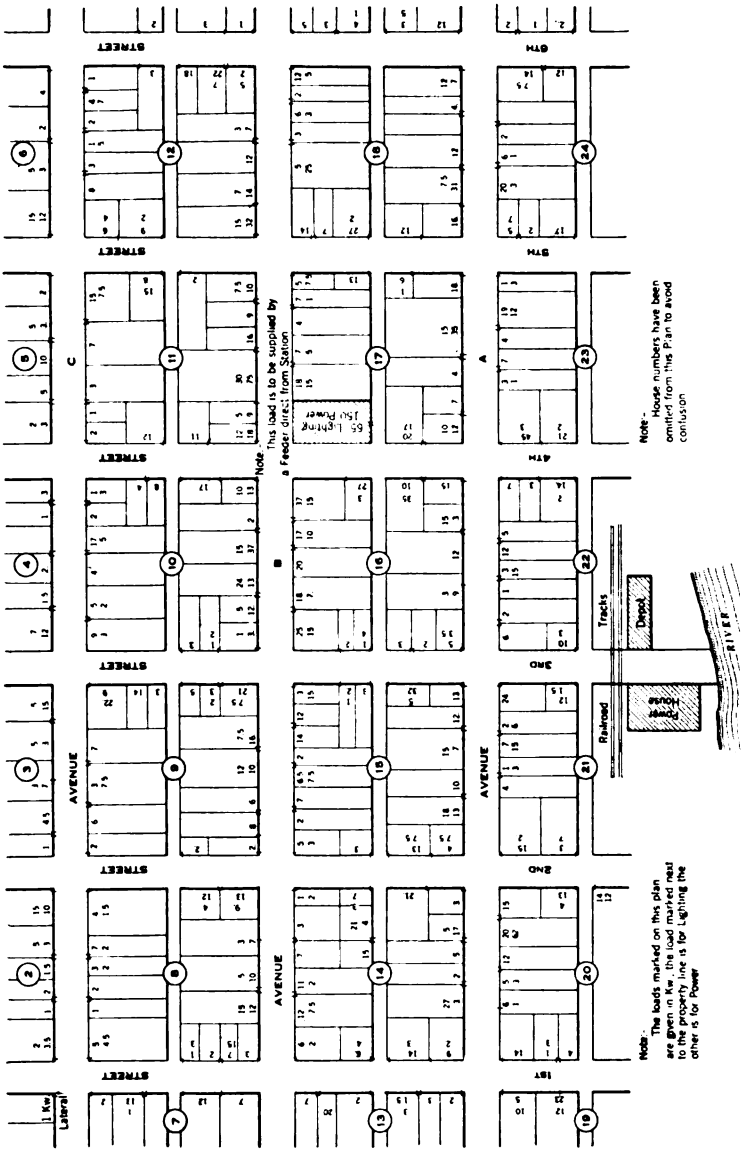

FIG. 2—LOAD MAP

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(particularly in alleys and the less important streets) so as to avoid considerable conduit construction.

The proposed location of the laterals in each building should be shown on the plan for the secondary systems for light and power. A study of these locations together with the street light conduit layout will often show where slight changes in one or the other will permit considerable saving, even when changing some laterals will increase the cost of the inside wiring.

Owing to the fact that the grouping of consumers, in a district, will usually be different on an underground system than it was on the original overhead system it is practically impossible accurately to determine what the demand and diversity factors will be for the new system. A distribution system for either lighting or power usually consists of the following sub-divisions:

Primary feeders to centers of distribution.

Secondary feeders supplying the transformers.

Secondary mains supplying the service laterals.

Service laterals supplying the consumers.

In small systems the secondary feeders are not required, as the transformers are connected directly to the primary feeders.

The size of cables to use for the laterals is easily determined, the principal object is to restrict the number of sizes of cable as much as possible, using about three sizes for the whole system, and if possible, making the largest size used for laterals the same as one of the sizes used for secondary mains.

Aside from the laterals it is evident that the secondary mains receive less benefit from the diversity factor than any other part of the system. It is also evident that any increase in the load will directly affect the mains which must be large enough to maintain satisfactory voltage for all consumers connected to them.

On the one hand is the diversity factor tending to reduce the size of the mains and on the other hand the probable increase in load which must be provided for, tending to increase the size of the mains. As not only the first cost but the interest on the investment depends on the size of the copper, it is important that these two conditions be given careful consideration and it is in cases of this kind that the engineer must be guided by experience and his knowledge of the situation.

There is one point that should be remembered in determining the size of cable to install for secondary mains, particularly where they serve a number of consumers in a business district.

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Owing to the fact that the service laterals are spliced directly to the mains at frequent intervals it is very expensive to replace them and the old cable, being in short lengths, is of little or no use except for its junk value; it is therefore advisable to make all secondary mains of ample size to provide for the total load that can reasonably be expected and use the best kind of cable, either varnished cambric or rubber insulated, for all secondary mains and laterals that terminate in junction or fuse boxes.

The load in the district should be divided as equally as possible into a suitable number of distribution centers so that one size and style of cable can be used for all of the feeders, as this permits standardizing the equipment and requires less cable being kept in stock for emergency purposes.

The feeders being generally small cable and having few or no taps on them can easily be replaced by larger cable and the old cable is in sufficient lengths to be used elsewhere. Instead of installing a larger cable to replace a loaded one it is generally better to install an additional feeder to another center of distribution, using the standard size of cable.

Where the requirements of the system demand the use of two-conductor cable it is advisable to have it made up in round form instead of the flat, or figure 8 style, as it is practically impossible to train this latter style without kinking it.

A careful study of the conditions under which underground distribution systems operate, particularly in medium size or smaller cities, has convinced the writer that the safest guarantee of reliable, efficient, and economical operation is to install cable and equipment, as far as the conditions will permit, under the following general rules.

Service Laterals. Use either cambric or rubber insulated cable, spliced directly to the secondary mains, and terminated in water-tight fuse boxes on the consumers property. (The number of laterals taken out at one splice will depend on the system; for single-conductor cables four laterals can be taken out, but two is about the limit where three conductor mains and laterals are used.)

Secondary Mains. Make these cables of ample size to provide for all the growth that can reasonably be expected. Use either varnished cambric or rubber insulated cable for all secondary work where cables terminate in subway equipment.

Primary Feeders. These cables derive the most benefit from the diversity factor, are comparatively long lengths, and have

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few taps on them, therefore are less subject to damage than the rest of the cables and are easily replaced with small financial loss. Small reserve capacity is all that need be provided for this class of cables.

Paper insulated cable can be used to advantage frequently at considerable saving providing that the ends are properly terminated in compound-filled potheads or varnished cambric or rubber insulated tails used for connecting to the equipment.

Personally, the writer does not approve of using any paper insulated cable on distribution systems, except on cases where the emergency facilities are such that the failure of a feeder cannot cause a serious interruption to the service.

In small companies, where competent cable men are not always available, the use of paper insulated cable on the distribution system is not advisable, it is however, well suited for high-tension feeders and tie-lines.

Subway Equipment. Due to the liability of being submerged occasionally and the limited space usually available, for its installation, subway equipment is probably the most prolific cause of trouble on underground distribution systems, and the greatest care must be used in selecting and installing it.

The best insurance against trouble from this cause is to provide reliable sewer connections to all manholes and vaults in which subway equipment is located. Separate the primary and secondary equipment by placing the transformers, primary fuses and switches in a vault (preferably located under the sidewalk adjacent to the manhole in which the secondary junction boxes are located.) This arrangement reduces the length of the secondary mains, which are usually large expensive cable, and lessens the liability of a burnout on the primary equipment damaging the secondary network. See Fig. 3.

The object in placing the vaults under the sidewalk is that it is seldom possible to secure sufficient room in the street also there is less liability of the vaults being flooded from surface water and they are more accessible in the winter when the ground is covered with ice and snow. This method of construction is more expensive than placing all of the equipment in the manholes but the added security is well worth the expense on an important installation.

Subway transformers should not be set on the floor of the vault but should be raised so that the air can circulate under and around them. Where more than 200 kw. of transformer

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capacity has to be installed in one vault it is advisable to provide ventilating pipes from the vault to a pole or side of a nearby building.

Subway junction and fuse boxes should not have slate or marble bases, but use ebonite or similar material that will not absorb moisture. All boxes should be subjected to an insulation test before being installed. Barriers should be provided between terminals of opposite polarity.

The iron work of all subway equipment should be permanently grounded to a reliable ground rod, plate, or if possible, to the city water pipe system. In large vaults, where there is considerable equipment, at least two ground connections should be provided.

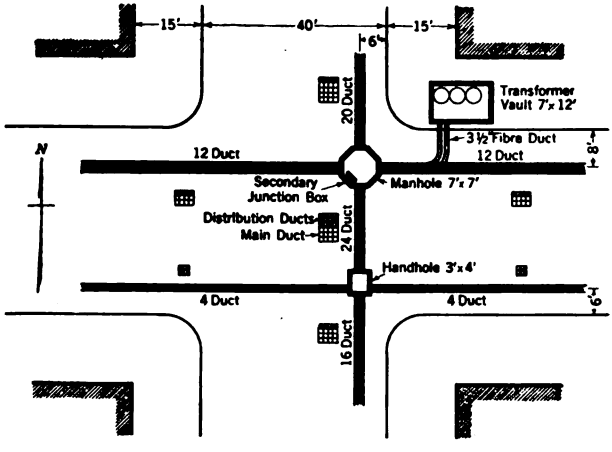

FIG. 3

Installing Cable. Assuming that all cable has passed the usual factory test, it is seldom necessary to subject it to another test before being installed unless there is some evidence that it has been damaged in transit. The conditions under which the cable is purchased and installed will, however, generally decide this point.

Use skids in loading and unloading reels, never drop them off of the truck. Place reels as near the point where they are to be used as possible. When reels must be left on the street for some time they should be securely blocked or preferably wired to a pole to prevent their being rolled about. Care should be taken not to place reels where they will interfere with hydrants, or obstruct manholes, water gates or traffic.

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Never handle paper insulated cable when it is cold. In cold weather it should be kept in a warm place until it is to be installed. Paper cable should not be bent shorter than eight times its diameter and should be warmed before bending.

Always provide sufficient men and power to safely handle cable during installation, when the cable is started in the conduit try to maintain an even steady rate of pulling. For heavy cable it is advisable to use grease or powdered soapstone.

Ends of cables should be kept sealed until ready to be spliced. Cables should not be left hanging from the duct mouth, but should be supported on hangers with as little bending as possible. The final bending and training of the cables should be done by the splicer when joining the sections.

When installing a new system, all lengths of cable should be bonded together temporarily as soon as they are installed. As soon as the cable system is completely connected up tests for electrolysis should be made of the whole system and proper measures taken to protect the cables in case of necessity.

The arrangement of cables and equipment in the manholes and vaults must be carefully planned to secure neatness and ample space in which to work and operate the equipment with safety.

All cables and equipment should be plainly marked showing the operating voltage and system it is used for. Where single conductor cables are used on three phase circuits they should be distinguished by different colors as this will prevent mistakes in making changes as only cables of like colors should be connected together.

While it is admitted that it is impossible to install a system that will be entirely free from trouble, it is possible, by carefully designing the system to prevent many of the faults that are a constant source of trouble on many systems.

Conduit System. The conduit system should be designed to serve the electrical distribution system as previously designed, This statement may, at first, appear to be a self evident fact, but unfortunately many conduit systems are not arranged to properly, and economically provide facilities for installing the proposed cable system. It is not an uncommon practice to install a conduit system based on a general assumption of the actual requirements of the electrical system.

The writer has seen conduit systems in which it was absolutely impossible to install the distribution system as it had to be

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operated, and which had to be partially rebuilt before the cables and equipment could be installed. These are no doubt exceptional cases but it shows the importance of a definite method of procedure in designing an underground distribution system.

It is a common practise in designing conduit systems to select streets or alleys having the cheapest pavement in which to locate the conduit, and then attempt to fit the electrical distribution to this location, and the result is invariably unsatisfactory and the saving in the cost in repaving is frequently exceeded by the additional cost of cables, and the total cost of the system thus increased.

It should be realized that a properly designed and constructed conduit system is a valuable property, and a permanent structure having little or no depreciation, and its importance in the supply of electrical energy warrants the greatest care being taken in its design and construction.

Conduit systems that are to serve high-tension or tie-lines between substations can be located so as to avoid the more expensive pavements, but conduit used exclusively for distribution systems should be located so as to best serve the electrical requirements regardless of the kind of pavement on the streets or alleys.

In a conduit system used exclusively for distribution (where all wires must be placed underground) the best location is usually in the streets. In cities having an alley in each block there is a strong tendency to locate the conduit in the alley.

The desire to utilize the alleys is based on the fact that the pavement is usually less expensive, and as the majority of pole lines are in the alleys the buildings are supplied from the rear, therefore if the conduit is located in the alley there will be less expense for changing the inside wiring to meet the new distribution system At first sight these advantages appear so great as to warrant the selection of the alley; there are, however, serious disadvantages to this location.

The alleys are usually from 16 to 20 feet wide and are generally fairly well occupied by water, gas and sewer facilities, and not infrequently, by one or two telephone conduit systems (which are usually installed before the electric light wires are placed underground) and the space available is, therefore, very limited.

The rear building line is very irregular, many buildings do not extend back to the alley, and frequently there are small sheds or extensions in the rear or the main buildings. The length of rear

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laterals would be greater than front ones and the difficulties and cost of installation considerably more; the greatest objection is that the rear laterals would not be permanent in many places but would have to be changed whenever any new building construction or changes were made.

Where alleys are located in the business section of a city they are usually used by the merchants for receiving and shipping goods and are subjected to a heavy traffic, considering the limited space. The merchants are practically all consumers of electric power and will strongly resent any interruption to their trucking facilities.

Owing to the limited space in the alleys, and the amount of traffic, it is practically impossible to store any material in them, consequently all material used on the conduit system must be stored in the adjacent streets and usually wheeled in by hand. This work and the excavation for manholes, removal of surplus material etc., will practically close the alley to traffic and the inconvenience of doing the work will greatly increase the cost of construction.

There is another serious objection to using the alleys. An average block, in cities having alleys, is about 300 by 300 ft. (91 by 91 m.) and usually has at least twelve separate buildings in it, in the business section there are generally more. When the distribution system is located in the alleys all of the buildings in a block are supplied from one secondary main which practically doubles its size, and the number of laterals that must be connected to it require frequent handholes in order to reduce the length of the laterals. This entails more complicated and expensive splices, cuts the main into short lengths, and in case of serious trouble puts the whole block out of service.

As a general rule, with the single exception of requiring less conduit, the alley construction is less desirable than a system installed in the streets. This statement applies to the business district of a city. Where overhead laterals can be used in a residential section the alleys are preferable for the location of the conduit, and as the traffic and obstructions are usually considerably less in such sections, the construction cost will be correspondingly less, depending on the pavement.

Before making the conduit design it is necessary to plot the location of all car tracks and existing sub-surface obstructions, in order to determine the most suitable location for the new system. While it is known that the records of sub-surface con-

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ditions are seldom accurate still a study of these records and the location of water gates, sewer manholes and other surface indications will permit a fairly accurate map being prepared.

Where there is any doubt regarding space being available for the conduit and manholes it is advisable to dig test holes, and if possible they should be dug at the points where it is proposed to locate manholes.

The design of an underground distribution system is not a difficult matter if handled in a systematic manner and the result obtained from a thorough study of the conditions will fully warrant the engineering expense necessary to prepare accurate plans covering every detail of the work.

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SOME FEATURES OF DOMESTIC ELECTRIC COOKING AND HEATING

BY H. B. PEIRCE

ABSTRACT OF PAPER

Although electric cooking and heating has always been considered possible, it has only recently become popular; hence the engineer is found unprepared with information on the characteristics of the load.

From tests made on a number of domestic cooking and heating installations, it would appear that electric cooking has a better load factor than a lighting load and that this load factor improves as the number of ranges increases.

The errors incident to these tests are discussed.

The demand factors on being plotted against number of ranges appear to follow a logarithmic curve which may be accounted for by the fact that a modification of the law of probability would no doubt determine the probable coincident demand of a number of ranges and that this law is a logarithmic function.

Suggestions are made for the checking of these results by others.

In the heating field, the effect of water heaters superimposed on range loads is discussed in relation to their effect on the central station loads and income.

SINCE the use of electrical energy first developed, the possibility of successful heating or cooking by heat, generated electrically, has never been questioned; the problem has always been—can it be done at a profit to the central station, with energy sold at a price low enough to put electricity in competition with other fuel?

Today we find a sudden stampede for this ideal fuel, but we find the electrical engineer unprepared to solve the problems of heating and cooking electrically.

It will be the province of this paper to show what may be expected by a central station after there has been developed a load of ranges and water heaters, and along what lines engineering assistance is needed to solve certain knotty problems connected with this phase of the industry.

First, to consider the effect on the central station of a cooking and heating load. It would be natural to expect that a cooking

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load would have a load factor considerably lower than the lighting load in the same community. This we find is not the case and it further appears that there is a greater increase in load factor in a cooking load by reason of an increase in number of consumers served, than would be gained in a lighting load by such an increase of consumers.

These deductions are the result of a number of tests made on actual water heater and range installations in homes using electrical energy for cooking and water heating.

The tests consisted of installing recording ammeters on the various cooking installations and reading the charts taken therefrom to the nearest five-minute interval; these readings were then assembled and the total load for any day at any hour determined.

A number of assumptions were of necessity made in securing these composite loads.

First, it was assumed that the clocks of the various meters were synchronous. This is in error for two reasons; (a) the charts were not all taken on the same calendar day but were taken at different seasons for different ranges and superimposed according to the day of the week on which the readings were taken; (b) the clocks were not absolutely accurate either as to time of day or as to speed.

Second, the readings were taken on a five-minute interval; this meant that the reading for the interval had to be integrated by inspection, which was, of course, difficult to do with much accuracy, particularly in view of the fact that the swing of the needle on these instruments was considerable.

The first opportunity for error would appear to have more weight than it proved to exhibit in practise, since a set of charts for a week, taken at one time of the year, have a strong resemblance to similar charts taken during a week at another season. In other words, in the community observed, the habits of the public as it concerns the preparation of meals, appears to be uniform at different seasons of the year. The opportunity to run into error by inaccuracy of the clocks is so slight as to be incommensurable with the accuracy of the results which at best are only approximate.

Curves shown in Figs. 1, 2, 3, 4, 5, 6, and 7, exhibit the daily load of 42 ranges of assorted manufacture and varying capacity from 2.5 to over 6 kw. As the coincident maximum demand of these ranges can be obtained from the curve, and as

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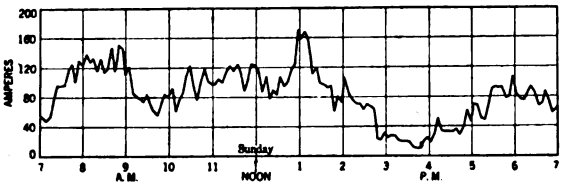

FIG. 1—COMPOSITE RANGE LOAD CURVE

Number of ranges 42—Connected load 155.4 kw.—maximum demand 20.07 kw., voltage 116.

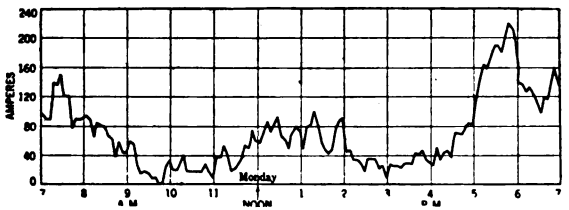

FIG. 2—COMPOSITE RANGE LOAD CURVE

Number of ranges 42—connected load 115.4 kw.—maximum demand 27.75 kw.—voltage 116

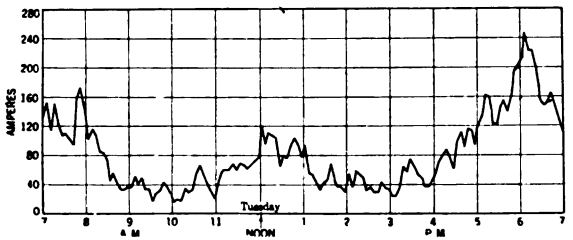

FIG. 3—COMPOSITE RANGE LOAD CURVE

Number of ranges 42—connected load 115.4 kw.—maximum demand 28.65 kw.—voltage 116

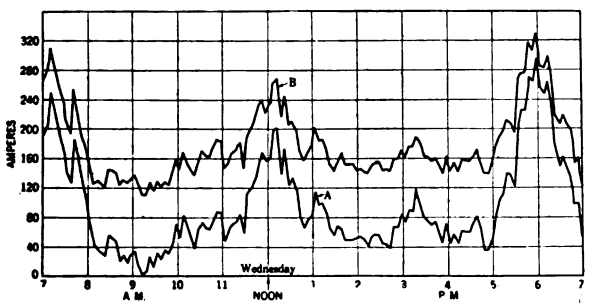

FIG. 4—COMPOSITE RANGE AND WATER HEATER LOAD, CURVE "B"

Number of ranges 42—number of water heaters 21—connected load ranges 155.4 kw.—connected load water heaters 12.18 kw.—maximum demand 37.47 kw.

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the total connected load is known, the demand factor can be computed. As the average kilowatt-hour consumption of each range is known, it is also possible to figure the combined load

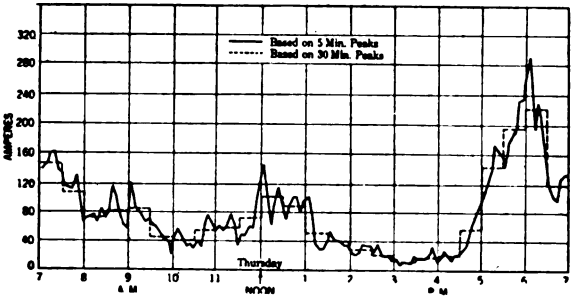

FIG. 5—COMPOSITE RANGE LOAD CURVE

Number of ranges 42—connected load 155.4 kw.—voltage 116—maximum demand (5 min.) 33.75 kw.— max. demand (30 min.) 25.63 kw.— demand factor 5 min. peak 4.6— demand factor 30 min. peak 6.1— demand factor 30 min. peak (Wed.) 5.5

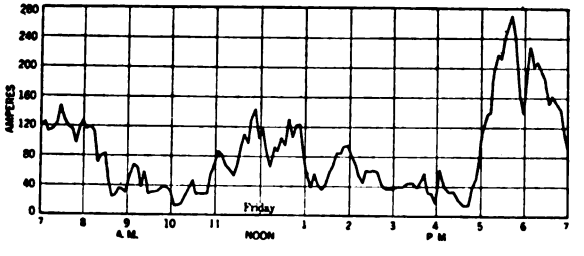

FIG. 6—COMPOSITE RANGE LOAD CURVE

Number of ranges 42—connected load 155.4 kw.—maximum demand 31.43 kw.—voltage 116.

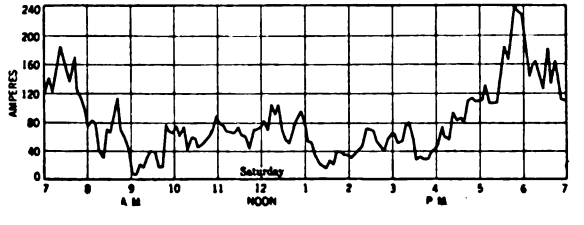

FIG. 7—COMPOSITE RANGE LOAD CURVE

Number of ranges 42—connected load 155.4 kw.—maximum demand 27.96 kw.—voltage 116.

factor of the group. These values show that even with as small a group as 42 ranges, the demand factor is 4.5; with 25 ranges. it has been found never to be less than 3.5.

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It might be expected that the demand factor would increase as the number of ranges increases; this is shown in Fig. 8, where a number of groups of ranges have been observed for demand factor and these demand factors plotted as ordinates with the number of ranges as abscissas.

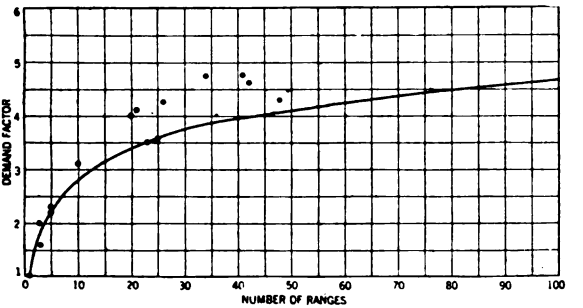

FIG. 8.

The result is a shot-gun diagram which interests us not so much in its upper limits as in its lower limits; that is, the worst condition which we are liable to experience in any given installation is that for which we must make provision. The curves

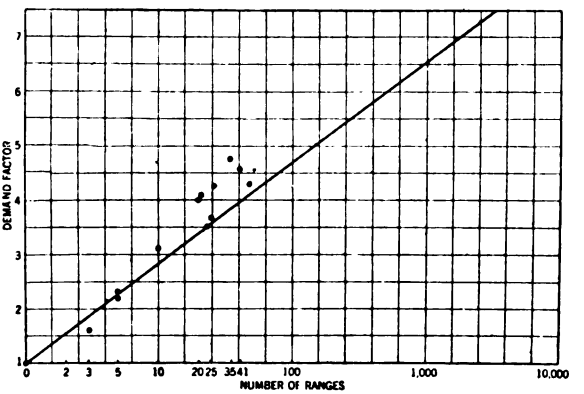

FIG. 9.

through the points on the lower limits appears to have logarithmic characteristics and by plotting the points on logarithm paper (Fig. 9) we find that they approximate a straight line, that is, they follow roughly a logarithmic curve.

Such a curve would have infinity as its upper limit and this

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we know is impossible, as the demand factor can never exceed the reciprocal of the average individual load factor.

It is possible that this last statement requires a word of explanation as it is not self-evident.

Consider ten installations, each with a demand of one kw., and an individual load factor of 10 per cent. The greatest demand factor, 10, would be secured when each individual installation was turned on for a tenth of the period and then turned off while a second was thrown on the line. The result would then be a demand never exceeding one kw. and a load factor of 100 per cent for the entire group.

Let us apply this to the ranges tested. The connected load, which for convenience may be assumed as the individual maximum demand of each individual range, will average about five kw. on the present types of electric ranges. These same ranges will each average a consumption of about 100 kw-hr. per month; that is, the individual installation will have a load factor of about 2.8 per cent. The reciprocal of 2.8 per cent, or 36, is then the maximum limit of the demand factor on ranges of this type. To reach this value it would be necessary for the combined load factor to be 100 per cent, which is of course impossible under present conditions as there are hours during the day in which there are no cooking operations being conducted.

As an academic example this result might be secured from a central station supplying energy to consumers extending around the globe in a zone of perfectly uniform density. If the logarithmic curve is followed out to demand factor 36, it will be seen that this amounts to an infinite number of ranges to all extents and purposes.

The theory, that demand factor will increase in accordance with a logarithmic rule will appear more logical when it is remembered that diversity and demand factor depend upon the theory of probabilities which has logarithmic characteristics.

To get the greatest practical good from this theory it should be checked in a number of different localities by different observers and the results compared; then, from the results, a rule adopted that would permit the probably coincident demand of a number of ranges to be more accurately predicted than is possible at the present time. These results should be of sufficient accuracy to enable the various electrical rules to be based upon them, so that it would not be required that excessive feed cables be provided for the care of apartment houses equipped with

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electric ranges, and so that the proper sizes of feeders and transformers for serving a load of ranges would be better computed by distributing engineers.

It will be noted that the demand factors have been figured in the computations so far made on the basis of a five-minute peak. For practical purposes such a peak is unnecessarily brief so that the effect of a 30-minute peak has been indicated on Fig. 5 by a dotted line which represents the results of measuring the demand by means of a demand meter of the type that integrates a load over a series of definite half hour periods.

Integrated peaks of half-hour duration will, of course, make the demand factor greater. This should be borne in mind in comparing charts taken in different cities.

In making comparisons, there should also be noted the class of people by whom the ranges are used. Those referred to in this paper are representative of all the classes that will eventually do their cooking electrically. They include families with incomes of less than $100 per month and homes in which the bill for current is a minor consideration. The apartment house dweller is, however, not as well represented as he should be. To show the effect of such consumers in helping to improve load factor, the demand factor of the ranges of one of the apartment houses in Salt Lake City is shown in Fig. 8. This demand factor, it will be seen is far in excesss of those secured from ranges installed in homes in Spokane, the city in which the individual tests were made. At first, this does not seem logical, as one would think that the dwellers in the same apartment house would come from the same walk in like and would be likely to do their cooking at the same hours. The answer probably is that they do less regular cooking than do the families in their own homes.

Another point that should be commented upon before leaving the subject of electric ranges is the average monthly consumption of the individual ranges in kilowatt-hours. This has been referred to above as being about 100 kw-hr. It is true that the value, 100 kw-hr., represents approximately the average condition, but to say that this is the probable consumption of any particular electric range, is quite another thing; the truth of the matter is that the consumption seems to vary between the limits of 50 and 250 kw-hr. while in exceptional cases the energy consumption of a range used by a farmer has been known to exceed 400 kw-hr. during a single month. This condition appears

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generally during the season of harvest when there is a large number of hands to feed. Attempts have been made to predict the consumption of a range by the size of the family by whom it is used; this the writer believes to be unsatisfactory as there are wide variations in habits between families of equal size.

It will be noted that for the ranges observed the daily peak occurs very nearly at 6 p. m. In other words, it will coincide closely with the lighting peak. This is unfortunate, but when it is remembered that with a fair number of ranges in use, the demand factor will probably be 8, the feasibility of making this business profitable with a low rate per kilowatt-hour becomes clearer.

For instance, if we assume a monthly consumption of 100 kw-hr. per range, an average individual demand of 5 kw. and a demand factor of 8, we get the following results with a rate of 3 cents per kw-hr. for energy:

Revenue per range per year	$36.00
" " kw-year of range demand	7.20
" " " " " station demand	57.60

So far this paper has dealt only with the electric range; the next point to be considered will be the heating of water for the home.

A supply of hot water is essential to the satisfactory use of the electric range; that this can, in many instances, be accomplished electrically, is not questioned. The problem is, how it shall be done.

To compete with coal, wood and gas, for hot water heating, electricity must be supplied at a very low rate. This can only be done by securing a high load factor for the service; by taking the supply from valley hours; or, by limiting the use of the heater to those hours when the range is not in use.

A high load factor can be secured for this service by installing the heaters on flat rate and assuming that they will be used continuously; this has the disadvantage of superimposing their load on the existing peak. The revenue they return must then be sufficient to yield enough per kw-year to pay for all the fixed charges depending upon maximum demand at peak.

The disadvantage of limiting the use of water heaters to the valley period of the system load is that a very large amount of hot water must be stored, as in most instances the valley hours are not of very long duration and occur at a time when there is no need for hot water. The result is that if the hot water

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supply is depleted during the day, there is no alternative for the consumer than to wait until the next day for more hot water. A further disadvantage is the expense of an installation to supply such a system. Time switch, large capacity heater, and large, well-insulated storage tank, all will be found to amount to a considerable sum.

The third method of limiting the use of the heater to the hours when the range is not in use, has some of the advantages of both systems with less of their disadvantages; it can be controlled by a double throw switch or by a special rotary snap switch now on the market for that purpose. The diagram of wiring for such an installation is shown in Fig. 10. The effect of such a water

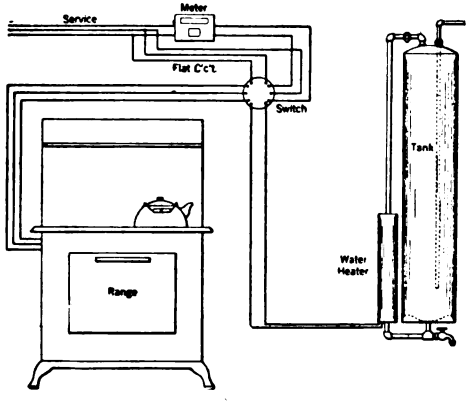

FIG. 10—WIRING DIAGRAM FOR ELECTRIC RANGE AND WATER HEATER CONTROLLED BY SPECIAL SWITCH

heater load when superimposed on a load of ranges is shown in Fig. 4.

It will be seen from the curves on this figure that a load of 42 ranges gave a peak of 33.41 kw. when operated without water heaters, (Curve *A*). When 21 of the ranges were equipped with 600-watt water heaters on double throw switches, the peak was only increased to 37.47 kw. (Curve *B*).

A common rate for a 600-watt water heater operated in this fashion is $2.00 per month and if the ranges use an average of 100 kw-hours each per month the rate for energy being 3 cents per kw-hr. they would return a revenue of $36.00 per year per range or a total revenue of $1512.00 for the 42 ranges. These ranges show a demand of 33.41 kw. which means a revenue of $45.00 per kw-year when operated without water heaters.

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If 21 water heaters pay $24.00 each per year, we would get an additional revenue of $504.00, or a total of $2016.00 from the ranges and water heaters combined. The demand is now raised to 37.47 kw. which gives a return of $53.70 per kw-year. It is conceivable that the addition of such a water heating load might make an otherwise unprofitable installation of ranges profitable.

Regarding the size of heater required for this purpose, there are few accurate data which can be offered. The 600-watt size appears to be the smallest that will work satisfactorily while it is seldom that a heater larger than 1.5 kw. is required. The number of people in the family, their habits, the size of the storage tank, the system of hot water distribution, all affect the results.

Problems dealing with the electric heating of buildings are so large that they are felt to be beyond the scope of this paper. It is undoubtedly possible to secure a load of this nature when cheap power is available, in a locality whose climate is not so rigorous as to make the cost of heat units the main criterion by which the efficiency of the system will be judged. The writer feels, however, that his experience is so limited in this regard that anything said by him at this time might do more harm than good to the ultimate development of this field.

Another field that will bear investigation is the question of how best to distribute for a range and water heater load. The use of individual transformers for each range with no connection between the secondary lines is objectionable by reason of the high cost of installation. The use of safety devices between transformer secondaries for providing safety to adjacent transformers connected in multiple may make it possible to secure greater benefit from the large diversity that undoubtedly does occur between different groups of these appliances.

The question as to how the electrical engineers of today can best promote the development of electric heating and cooking and whether there is any phase of this subject that has been neglected by the Institute to the detriment of the electrical heating and cooking field and to the standing of the profession of electrical engineering is worthy of our attention in closing.

The electrical cooking of food does not appeal to the average engineer as worthy of his august attention, as it smacks too much of the work of the humble house maid. The big problems of large transformers and high-tension transmission appear far more important.

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Is this position well taken? Is not the service of society the main object that should stimulate the engineering profession and is there any problem more worthy of the attention of the engineer than the problem of supplying food to the citizens of the community? Certainly this is a problem far more important than the problem of supplying the luxury of light.

The humble work of heating water is certainly as vital to the advance of the community as any that may, on the surface, appear more poetic by reason of the handling in one unit of a large capacity of power. The cake of soap has been considered an index of the progress of civilization, but of what little use is the soap without hot water to use it with.

The standards of the Institute have been looked upon by both the engineers of this country and by those abroad as indicative of the progress of the art and as representing the formulated practise of the country. Be it to our shame that there is in the rules of standardization no mention of the proper installation of electric cooking and heating appliances, and but one brief mention of the insulation of the heating and cooking appliances that are now in use on the lines of every central station in this country.

In the early history of the art the engineer with mistaken ideas of dictating the possible for the practical, developed heating and cooking appliances that impeded the growth of the use of electrical energy for the saving of labor in the home. Be it to the credit of a few men of wide vision that this is not the case today.

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(Subject to final revision for the Transactions)

TESTING FOR DEFECTIVE INSULATORS ON HIGH TENSION TRANSMISSION LINES

BY B. G. FLAHERTY

ABSTRACT OF PAPER

This paper discusses the importance and necessity of field tests on high-tension insulators and three methods of making such tests, viz.; with the oscillator, the megger, and the telephone receiver. The latter is described in detail, and some data given on its development and use on a 60,000-volt line in western Washington, covering a period of 2.5 years. Laboratory checks on 13 of the defective insulators located, are given, and an approximate relation established between the telephone receiver test and the break-down value at 60 cycles. Success of test is shown in note on its effect on operation.

Figures from regular routine tests show percentage defect on various lines, and cost of locating and replacing defective units is given at $1.13 each (labor only), and cost of testing only was 2.3 cents per insulator on the line.

A method of studying the rate of depreciation is outlined and some data given in illustration.

INTRODUCTION

MOST of the literature dealing with the failure of insulators on high-tension lines, treats almost entirely with the question from the point of view of improving the quality of the future insulator by various means of manufacturing improvements and specifications for testing before putting into use on the line. It does not deal to any considerable extent with methods of locating defective insulators among the great number already in service. While it may be admitted, without question, that the evolution of better insulation for future use is the most important need, the treatment and handling of the large quantity of insulators already installed should not be neglected. In fact this problem becomes the most serious one to the operating man, both from the standpoint of preserving the continuity of service, and of conserving as much as possible the large investment in the stock of the insulators in use.

Formerly, there was considerable discussion and argument about the depreciation of the porcelain in line insulators, though

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the majority of recent opinion seems to deny the depreciation *per se* and attributes failures after a period of service to various causes; such as inherent faults in the part as it comes from the firing, troubles due to improper cementing together of parts, or the use of cemented-in iron pins, causing unequal expansion. There is, however, no denial of the fact of deterioration of the insulator considered as a unit, *i.e.*, failure after a period of service. Undoubtedly a great deal can be, and has already been done to improve the quality of the porcelain; and by laboratory tests, to weed out the defective units in the process of manufacture and distribution. To this end the Transmission Committee has evolved the " Specifications for Insulator Testing ", dealing almost entirely with factory tests.

More important to the man now operating high-tension lines is some means of locating the defective insulators he already has on the line, thus affording him an opportunity to improve his factor of safety, and to preserve continuity of service, to which insulator failures have been in the past such a menace. Such a device, or devices, should be cheap, both as to first cost and as to methods of use; and should be reliable within practical limits. Too much expense either in first cost, or labor involved, could not be put into this class of work without approaching the point where it would be more economical to put in new insulation throughout. As yet, only three methods of testing insulators already in use on the line have been suggested; the oscillation transformer, the megger system, and the use directly of the telephone receiver.

The use of the oscillation transformer is recommended by Prof. E. E. F. Creighton and clearly outlined as to connections and adaptation in the PROCEEDINGS of the A. I. E. E. (February, 1915, page 302). The data given in the discussion indicate that it is very satisfactory as a high-frequency test and capable of being made very severe. Its availability and simplicity as a laboratory method for new insulators or those that have been removed from the line is evident; but its adaptability to service in the field is not so evident, presenting many difficulties. In the first place, in testing insulators on a line in actual service, it would be necessary to take the line out of service during the period of test; or to remove a quantity of insulators from the line, crate, transport, uncrate, test and replace on system, making the test prohibitive in cost. Also in attempting field work, a considerable crew would be required to handle and

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FIG. 1 [FLAHERTY]

FIG. 1a [FLAHERTY]

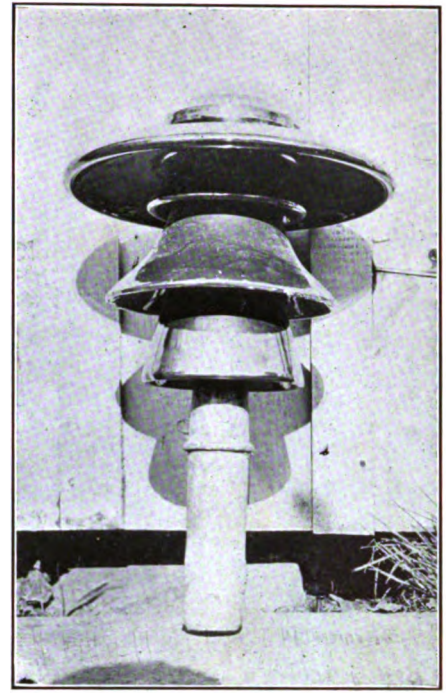

FIG. 4 [FLAHERTY]

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operate the apparatus and to make connections to each individual insulator, removing the line wire for the test. Another difficulty would be the source of current for the testing apparatus at all points of the line. These difficulties make the method impracticable for field work.

The megger test has become so commonly used throughout the country, especially on suspension insulator work, that it needs no description here. Mr. T. A. Worcester (*General Electric Review*, June, 1914, page 600) gives a thorough statement of the uses and limitations of this means of locating defective insulators. His main deduction is that it is not unconditionally reliable, being primarily a measure of the resistance, which may be practically "infinity" on a broken or punctured insulator unless contact is made directly with the defect and the latter is made conducting by the application of moisture. Another objection to the use of the megger for this purpose, is the necessity of "killing" the line under test for considerable periods and the use of a crew of men to make connections and remove the line wires from the insulators. It seems more particularly adaptable to testing the separate units of suspension type insulators.

The use of the telephone receiver in the detection of defective insulators is mentioned by Mr. M. T. Crawford (August, 1914, PROCEEDINGS A. I. E. E., page 1163), and it is with the development and use of this method that the present paper has to deal. Mr. P. H. Thomas (page 1205, same issue) says, "We must find some way of detecting bad insulators. That can partly be done by tests, but we need a few new tests." If it can be shown that the test is reliable to a reasonable degree, it is evidently the most ideal method yet suggested, in that the actual testing can all be done by one lineman of reasonably good judgment and hearing, and also without any interference with the operation of the line, *i.e.*, the test is made at line voltage and frequency.

APPARATUS AND USE

The apparatus as developed for use on wooden poles is shown in Fig. 1. The double head set receiver is used to the best advantage as it aids in excluding foreign sounds, and focuses the observer's attention more closely on the work in hand. Almost any telephone receiver is found to be serviceable so that patrolmen in their routine work may use the receiver in the portable test set which they carry with them to locate the worst

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cases of defect. Where greater sensitiveness is required, the two thousand ohm wireless set shown in the illustration is found to give the best results, with the two units connected in parallel. The flexible cord used for connections is fastened by a small nut to the lineman's spur at one end, this serving as the ground terminal; and by a double connector to the large stiff wire run through the bamboo stick and sharpened to a point for contacting to the pole; *i.e.*, shunting a portion of the current flowing in the pole, through the receivers to ground. This, with the lineman's spurs and belt and proper notebook constitutes all the equipment necessary for locating defective insulators on pole lines using pin-type insulators. For use on steel tower lines using pin-type or suspension insulators the modifications are slight, looking more toward the safety and protection of the observer than anything else. The upper terminal is extended to a miniature wireless antennae, either in the form of radial spokes of a wheel, or a circular plate, and is used to explore the electrostatic field in the neighborhood of the insulator instead of measuring the actual current flowing over and through the insulator. Slightly greater sensitiveness is necessary for these cases and a higher resistance receiver with the units connected in series is recommended. The principal difficulty with this method is in protecting the operator from accidental contact with the high-tension wires. This is accomplished by covering the terminal with an inverted basket of wooden strips of dimensions sufficient to give proper clearance of four times the needle gap spark value for line voltage to ground.

Two qualifications are necessary to the successful observer at this work; first, that he should be a good lineman, capable of going up and down, and working on the pole or tower near high-tension lines with quickness, steadiness, and assurance; and second, he should have good hearing. It is not especially important that he should be a technically trained man, although a little laboratory training and knowledge of electrical phenomena will help him considerably in the interpretations of the various sounds he will find throughout his experience of this work. The ordinary first class lineman of average intelligence can be taught by example to use the set and give a first rate judgment of defects indicated, in a few minutes time. Scientific truthfulness, *i.e.*, the faculty of setting down results as they actually come to him rather than as he believes he should get them, is also an important requisite. Absolute accuracy in

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keeping the records of the test is imperative if it is to be of any value in eliminating the defective insulators afterwards. Ordinary surveyor's field books are found to be most serviceable in use over the varied country which most transmission lines follow. The inspector in traveling along the line sets down the pole number and the result of the test on the ground. Four degrees of defect or leakage are arbitrarily assumed, namely, zero, first, second and third. The judgment of the observer must be depended upon to place properly the sounds heard. If the pole test indicates zero leakage it is not necessary to deal

INSULATOR TEST — TACOMA No. 1 LINE

Pole No.	Pole test	No. 1	No. 2	No. 3	Remarks
2585	0				Fife, Station, P. S. E. Ry.
87	3	3	3	1	Date: 4-10-16
89	0				Observer: McGandy
91	1	0	1	0	Weather: Fair, clear
93	0				Ground: Moist, tide
95	0				flat level.
97	2	1	1	2	
99	3	3	0	0	
2601	3	0	3	0	
03	0				
05	0				
07	0				
09	0				
11	3	0	1	3	
13	0				
15	3	3	2	1	
17	0				
19	0				
21	0				
23	0	0	0	0	Climbed as check on former test
25	0				
27	0				
29	0				
31	0				
33	0				Gardenville Station.

FIG. 2

further with that one. If any leakage is heard, the inspector proceeds up the pole and tests to each insulator pin, or slides the point out along the crossarm or up the pole top if apprehensive of danger from too bad an insulator. Beginning at the left hand crossarm position, and looking in the direction in which the line is numbered, the insulators are numbered clockwise over the pole top in the case of equilateral construction. In vertical construction they are numbered from bottom to top. If more than one insulator supports the wire in each position on the pole or tower, the respective units are given sub-letter designations, as 1-a. 1-b, for double construction. Fig. 2 shows

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a sample page from the standard note book used. Only one man is necessary for this work, but the practice so far has been to send along a helper who is ready to climb to the other's assistance in an emergency, and this man can expedite the work considerably by keeping the record.

Weather conditions have considerable influence on the testing work through their effect, both on the insulator itself, and the working conditions of the test apparatus. Rainy or foggy weather increases the leakage over the insulators, especially if there is a deposit of dust, smoke, or other foreign matter, to such an extent that the exercise of a good deal of judgment on these effects is necessary in testing to keep from condemning a great many good insulator units. If rain is falling it is impossible to use the testing set, as the drops about the head and receivers shut out all other sounds effectually; and work on "bad" insulators on the pole top becomes literally "hair-raising". The ideal time to make this sort of test is when the sky is clear and the ground slightly moist underfoot to afford a good ground connection.

Theory of Action

The discussion of the theory of action here advanced is based on the pin-type insulator on wooden poles, but may be adapted to the other cases. The pin-type line insulator may be considered as a resistance shunted by a number of small condensers connected between the line wire and ground, and some idea of the magnitude of the currents flowing in such circuit may be obtained from measurements already published. Just to show that the resistance component of the current over the insulator from line to ground is of an appreciable value for measurement in the telephone receiver, Mr. Ralph D. Mershon may be cited (Vol. 27, Trans. A. I. E. E.) as giving the power loss per insulator as between 40 and 75 watts at 50 kilovolts. From this it is readily seen that the effective value is sufficiently large to give considerable indication at 60 cycles, a-c., in an ordinary receiver, which is sensitive to a millionth of an ampere. Some idea of the relative magnitude of the capacity component may be obtained from Mr. Edward Bennett's statement (A. I. E. E. Proc. Vol. 32, page 310) of the capacity of a 40-kv., three-petticoat insulator at about 2×10^{-11} farads, giving a current on a three-phase, 40-kv. system of the order of 2×10^{-4} amperes effective.

Thus by shunting a portion of the high resistance path of

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the resultant current through the crossarm and pole to ground, it is seen that an effective current of the order of 3×10^{-4} amperes is obtained through the comparatively low resistance receiver. This means a maximum variation of current, positive to negative, of $2\sqrt{2} \times 3 \times 10^{-4}$ or 8.5×10^{-4} amperes in the complete sine wave cycle.

Over the perfectly good insulator this current is audible in the telephone receiver as a clear musical tone of the same pitch as the line frequency. If however, there is any defect, such as a crack, or a punctured petticoat, the leakage path is shortened, the capacity is changed, and the volume of sound increased considerably. If the defect is at all serious at the impressed voltage, a brush discharge effect becomes audible in the receiver as a scratching, spitting sound characteristic of such phenomena, before any evidence of it is given to the unaided eye or ear. On an ungrounded delta system, this sound can be heard to fluctuate as the neutral shifts toward or from the wire on the insulator under test.

The range of sound and variations, from the perfect insulator to the dangerously defective one, is very considerable, and capable of being subdivided into many more than four degrees selected, though they seem sufficient for all practical work. If more than one petticoat of a 60,000-volt, four-part insulator is defective, the noise of the brush discharge becomes so intense that it is unmistakable, though perhaps inaudible to the ear alone.

Many curious phenomena will present themselves to the observer who spends any time at this work, which can only be mentioned here, but may be used in further development or use of this same test. For instance, definite knowledge of the exact time of " killing " or " making the line alive " may be had by simply listening in the usual way at the bottom of the pole. Any disturbance on the transmission line is clearly audible in the test set, and the charging of lightning arresters miles away, is heard as distinctly as though near by. If considerable capacity is present on the pole top, through a number of insulators in parallel, an overtone of a very much higher pitch than the fundamental becomes audible, which is probably due to the presence of a higher harmonic.

No difficulty seems to be encountered by various observers in grading the sounds as to leakage indicated, though there may be a difference of one degree set down in the record by different

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persons when near the dividing line between two degrees. This is dependent on the judgment of the individual, and experience is the most valuable instructor in grading the defects accurately.

Checks of Method

The origination, and institution on the Puget Sound Traction, Light & Power Company lines, of this system of testing, in the spring and summer of 1914, followed a series of particularly severe interruptions to service during the winter of 1913-14, due almost entirely to insulator failures on that portion of the system which had been operating at 60,000 volts for about ten years. The effects of the apparently increasing number of failures were so annoying and cumulatively destructive that some method of locating the dangerous units became imperative. A number of tests were made on the defective insulators with a megger, but no satisfactory results could be obtained as it was necessary to actually find the flaw in the porcelain and then moisten it before any indication of less than infinite resistance could be gotten. A great deal of preliminary experimentation was done with the telephone receiver also, before it was adopted as a routine testing apparatus.

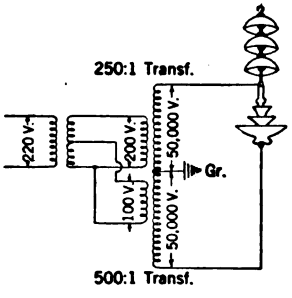

Fig. 3—High-Voltage Test

As a preliminary check on the accuracy, a pole was selected on one of the lines that had given most trouble during the previous winter, which carried insulators indicating in the test set all three degrees of leakage, as mentioned above. These three insulators were removed from the line and taken to the White River generating station, where a temporary high-voltage test set was rigged up out of the apparatus available. The insulators were kept as nearly as possible in the same condition as on removal from the line, and but a short time, perhaps a couple of hours, elapsed until the high voltage was applied to them.

The apparatus used consisted of a 50,000-volt oil-testing transformer and a 50,000-volt, 100-watt potential transformer connected in series on the high tension side, with the common terminal grounded. The secondary windings were energized from the local 220-volt service and regulation was obtained from the hand induction regulator on the oil-testing transformer.

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A new three-part suspension insulator, hung from the ceiling, carried one terminal of the set and the insulator under test was suspended by the pin from this point. To a piece of line wire fastened to the test insulator head with fine copper wire, was carried the other high-tension lead. A diagram of the connections is shown in Fig. 3, and the results of the application of high voltage in Table 1.

TABLE I.

PRELIMINARY HIGH VOLTAGE TEST AT WHITE RIVER, JULY 1, 1914.

Insulators taken from Pole No. 1739, Tacoma No. 1.

Ins. No.	Tel. test degree leakage	Volts at breakdown from trans. ratio
3a	3	63500
3b	2	84500
1a	1	Did not break down but showed distress at full voltage obtainable.

The maximum e.m.f. obtainable from the induction regulator for the secondaries of the transformer series, was 175 volts, giving 87,500 volts, (trans. ratio 500:1) on the high-tension side; if the effect of a possible phase angle difference in the two transformers were neglected. While not regarded as a rigid check, this test was considered a practical demonstration of the utility of the telephone receiver for locating defective insulators. It was felt that the argument, that the chosen insulators failed at a voltage at least not any greater than the values given, would hold; and that while further use would give more data, the test would be sufficiently reliable to put into use at once in clearing the transmission lines of the worst cases of defective insulators. A complete test was therefore run on two of the older lines, Tacoma No. 1 and Seattle No. 1, and the poor insulators taken off immediately afterwards.

No other source of e.m.f. higher than 60,000 volts was available in this section, than the rough set-up described above, until the placing in service of the 20 kv-a., 200,000/220-volt testing transformer at the University of Washington, built by Messrs. Dodds & Dashley in 1915. Through the courtesy of Dr. C. E. Magnusson and the University of Washington, the use of this transformer and the facilities of the university laboratory were offered in checking up the results of the test.

A group of insulators, ten in number, was selected from those found leaking in a test with the telephone receiver on the after-

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noon of February 17, 1916. On February 18th, these were removed from the line, and on February 19th, were transported by automobile to the University of Washington laboratory and tested to complete breakdown. The comparative results of the two tests are given in Table 2. The current to energize the transformer was obtained from an alternating current generator, whose voltage wave had previously been determined to be very close to the true sine curve. This machine was run by a 10-h.p. motor at a speed giving close to sixty cycles, and the voltage (generator) was controlled by varying the field of the d-c. dynamo used as an exciter for the a-c. generator. E.m.f. was measured from an instrument coil in the low-tension winding of the transformer and the high-tension voltage calculated from the turn ratio (10,000:1). Since the test the high-tension voltage has been checked by means of a sphere gap and found to be about 9200:1 in the neighborhood of 100,000 volts.

TABLE II
COMPARISON OF TESTS

Pole No.	Ins. No.	Tel. Rec. 3/17/16– Test, degree	Breakdown test, U. of W. 3/19/16.				
			Brush discharge		Breakdown		Petticoats punctured
			Volts		Volts		
			Turn ratio	Sphere gap	Turn ratio	Sphere gap	
2645	1	3rd	80,000	73,600	104,000	95,700	1st, 2nd, 3rd
2645	2	3rd	84,000	77,200	96,000	88,400	1st, 2nd, 3rd
2693	1	2nd	100,000	92,000	134,000	123,200	3rd
2693	2	2nd	80,000	73,600	116,000	106,800	4th
2709	3	3rd	80,000	73,600	100,000	92,000	1st, 2nd
2711	2	3rd	76,000	70,000	94,000	86,500	1st, 2nd, 3rd
2717	2	3rd	60,000	55,200	98,000	90,000	1st, 2nd, 3rds
2737	1	2nd	80,000	73,600	104,000	95,000	Ist, 2nd, 3rd
2737	2	3rd	50,000	46,000	80,000	73,600	1st, 2nd, 3rd
2759	1	3rd	75,000	69,000	120,000	110,300	1st, 2nd, 3rd

NOTE: Petticoats are numbered from top to bottom. Those not noted as punctured are the only ones over which the flash of power arc was plainly visible at breakdown.

In considering the results of this test and comparing with those of the preliminary check, there are several changes in conditions to be taken into account, chiefly effects due to weather. The insulators removed for the latter were tested during damp weather in the winter time, February, 1916, and in a tide flat location where they were subject to salt water fogs. Two days afterwards they were transferred to a warm, dry laboratory room for the breakdown test. The preliminary test was made on a

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very warm, fair day in July and high voltage applied to the insulators soon afterwards. The searching out effect of the moisture on the insulator faults in the former case being so much greater in the receiver, a change being made in the observer, and the increasing severity of requirement in grading the leakage, all being taken into consideration, the apparent discrepancy between the two tests does not appear to be so great.

Three important points are to be noted in the results obtained; first, that all, except one, of the insulators rated at second and third degree leakage chosen for the test failed at double the rated insulator voltage (60,000 volts) or less; second, the effect of the location of the punctured petticoats, *i.e.*, whether top, middle or bottom; and third, that every one selected by the test set as of second or third degree leakage shows one or more defective parts. Evident distress, shown by the beginning of the brush discharge, at or near the rated voltage of the insulators should also be noted. If we accept the state law requirements, not one of the entire group would be considered a satisfactory insulator on test, as every one punctured or flashed over at less than two and one-quarter times line voltage.

By scrunity of the results it is possible to place an approximate upper limit of puncture value for the third degree leakage insulator near one hundred thousand volts; and a consequent like lower limit for the second degree insulator, though of course in the very nature of the test there is no sharp dividing line between any two consecutive degrees. It was not possible to test insulators of lower than second degree leakage, on account of the temporary, makeshift nature of the terminals in use at that time on the testing transformer, rendering it impracticable to go above 135,000 volts. The installation of permanent condenser terminals will later render an extension of the check possible. Note should be taken also of the fact that all the second degree and highest puncture value insulators were those one or more of whose widest flaring petticoats were not punctured, but flashed over. A view of the type of insulator discussed in this test is shown in Fig. 4, cemented on a $2\frac{1}{2}$-in. (10 cm.) galvanized iron pin, as all were.

Results Accomplished

As mentioned before, a complete test was made July, 1914, on two of the lines giving most trouble during the winter 1913-14,

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namely, Seattle No. 1 from Sumner to the city limits of Seattle; and Tacoma No. 1 from Sumner to Tacoma city limits. Only the insulators recorded as third degree leakage were replaced, although the record is kept for all degrees for further data on the rate of depreciation. In April and May, 1915, a second test was made on these lines, and the third annual test was made in May, 1916. In March, 1915, a test was also made on two pole lines from Sumner to Electron, a distance of eighteen miles. Following is a tabulated summation of above mentioned tests.

TABLE III

SUMMATION OF TESTS

Line	No. of Ins.	3rd deg.		2nd deg.		1st deg.		Clear	
		No.	Per cent	No.	Per cent	No.	Per cent	No.	Per cent
Test 1914									
Tacoma No. 1	1716	100	5.85	155	9.05	216	12.6	1245	72.5
Seattle No. 1	3405	25*	0.735	49	1.44	29	0.89	3302	97.0
Test 1915									
Seattle No. 1	3405	82	2.4	68	2.0	45	13.2	3210	94.5
Tacoma No. 1	1716	85	4.96	60	3.5	17	1.0	1552	90.2
Elec. No. 1	2670	72	2.7	65	2.42	103	3.86	2430	91.0
Elec. No. 2	2670	224	8.4	75	2.8	105	3.94	2266	85.0
Totals									
1914	5121	125	2.44	204	4.0	245	4.8	4547	89
1915	10501	463	4.4	268	2.56	270	2.6	9458	90.2

588 removed from lines.

*First completely tested line.

NOTE: Decrease in first and second degree insulators in 1915 test was due to skipping poles of lowest leakage in order to locate most defective ones first for removal from line.

A close check on the labor costs of the complete operation of locating and replacing the 85 defective insulators on Tacoma No. 1 on the second test was made, and is here presented.

COST OF TESTING AND REPLACING INSULATORS

Two men testing, 5 days time @ $7.90	$39.50
Number of poles	558
Cost per pole	7.1c.
Number of insulators included in test	1716
Cost per insulator	2.3c
Total number replaced	85
Total cost locating and replacing	$96.35
Cost each	$1.13

Of course as the line insulation becomes better the costs will somewhat decrease, and vice versa, but the average cost of testing runs less than ten cents per pole over all kinds of country, and most insulation conditions on lines in operation.

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In conclusion should be given some data on the success attained in the elimination of troubles due to defective insulators, but this material is not in shape just now for presentation in definite form. The fact stands forth, however, that whereas in 1914 any ground on the system, arcing or otherwise, resulted in numerous insulator failures, burning off poles and crossarms, and even burning No. 0000 copper line wires in two on the lines mentioned above; since that time there have been only two cases of destructive insulator breakdown on these lines. The first one of these was on Thanksgiving Day, 1915, and was apparently due to a direct stroke of lightning, which stripped every bit of porcelain out of a three-disk, dead-end insulator on a river crossing tower at Orting on Electron No. 1 Line, leaving the pole top wire connected directly to the pole by the inter-linking hardware; and broke down a pin type insulator on the same wire four miles north of Orting, literally blowing the top of the insulator clear of the pin. Despite the fact that one line wire between Renton and Kent lay on the ground for some time until burned off above arcing distance, no other insulators on the tested line failed under the severe strain, although on other lines not tested quite a number did so. The second case of failure was February 2, 1916, on Tacoma No. 1, during the very severe sleet storm of that period and was caused by trees growing near the line bending over under the sleet load and grounding one wire numerous times at short intervals. It is also to be taken into account that the last two years have been a period of more severe storms, especially of lightning and sleet, than have been known in this district for many years.

Depreciation Data

Some effort is being made to collect data on the rate of depreciation of porcelain insulators through annual tests over the same lines, but completeness along this line will require more time and more standardized methods than have been used in the past. Considerable study and latitude in reasoning are necessary to correct interpretation of the records obtained in order to get a clear idea of the facts as to the rate of depreciation. For instance, the testing so far in this work has been done with the sole idea in mind of locating the *worst* insulators and improving the line insulation at once by their removal, so that very little attention has been paid to those of second degree leakage or less, and the records of them are not complete or exact. Another

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factor for which considerable allowance must be made is the personal equation of the observer, who in some cases is very liable to miss the indications of lower leakage, either intentionally as intimated above, or due to lack of keenness of observation. Then too, there is considerable chance for confusion of circuits of the leakage current, that is to say, if a pole top holds one very bad insulator, there may be some indication of leakage from the other ones, though the latter will show up as perfectly sound upon removal of the defective unit. All of these things are brought out in the accompanying depreciation list, which contains the results from three tests over the same line, each one being made by a different man, without any record of the previous survey.

TABLE IV

DEPRECIATION LIST TACOMA NO. 1 LINE

Tested	July, 1914			May, 1915			May, 1916		
Insulator Numbers	1	2	3	1	2	3	1	2	3
Pole Nos.									
2137	1	1	1	0	3*	0	1	1	3
2231	1	1	0	0	2	2	1	2	3
2333	1	1	1		Clear		1	3	3
2499	1	1	0	1	3*	0	1	0	1
2587	2	0	1				3	3	1
2609	3*	0	1	0	2	3*	0	0	0
2657	1	1	0	3*	3*	3*	0	0	0
2671	0	1	0	3*	3*	3*	0	0	0
2699	1	2	0	2*	3*	3*	0	0	0
2723	1	1	1	3*	3*	3*	0	0	0
2753	3*	1	1				0	2	1
2789	2	2	3*	3*	3*	0	0	0	0
2793	0	3*	0				3	0	3
2827	3*	3*	3*	0	0	0	0	0	0

*Insulators replaced immediately after the test was completed.

Pole No. 2137 serves as a good illustration of several of the points stated above. The first test, July, 1914, was made with more care than that of May, 1915, the lower leakage consequently being noted. In the latter test the depreciation and excessive leakage of insulator No. 2 so overshadowed that of the other two in the hearing of the observer, that, coupled with the main idea of locating the bad insulators only, the result was a record of zero leakage for insulators Nos. 1 and 3, although careful attention would probably have also designated them. The third test, May, 1916, after the replacement of No. 2 insulator, shows what is probably the effect of a confusion of the circuits, as it is conceivable that a portion at least of the leakage

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current from No. 3 insulator would flow along or through the crossarm to the pole, up the pole top to the receiver terminal and back through the receivers to the pole at a lower point.

Poles Nos. 2609 to 2827 show very clearly the improvement in insulation and the clearing up of the line from the replacement of the third degree insulators, whether singly or all three on the pole top. No. 2753 exemplifies the perfect insulation of insulator No. 1 two years after the replacement of a defective one, and the gradual depreciation of the other two. No. 2793 is a like example, but with much more rapid depreciation of the clear ones. No. 2789 shows the increase to third degree leakage from second in less than a year's time and the subsequent clear test a year after replacement. This table will give some idea of the method for studying the depreciation rate which is being planned on for the future.

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INSULATOR FAILURES UNDER TRANSIENT VOLTAGES

BY W. D. PEASLEE

ABSTRACT OF PAPER

The operation of a high-voltage transmission line involves changes in energy distribution that are very conducive to high-frequency disturbances and transients of very steep front. These are often superposed on the normal frequency voltage of the line in such a way as to impose great stresses on the insulators.

The mechanism of failure of an insulator is of great importance to those designing and operating transmission lines. This paper presents the results of recent investigations on the failure of insulators under impact and combined impact and normal-frequency voltages. Microphotographs of the resulting failures are included.

The breakdown of a dielectric involves energy which is a time function and the importance of the duration of the stress in determining the magnitude of the voltage necessary to puncture an insulator is discussed.

Due to the short duration of transients, insulators are often punctured repeatedly by them, the procelain in the puncture solidifying again on account of the small energy involved. These sealed punctures however weaken the insulator, lowering its dielectric strength materially.

The importance of the elimination of air holes and defects in the porcelain is shown.

Some essential features of a successful line insulator are stated.

INTRODUCTION

A PARTICULAR dielectric will be ruptured or broken down when the dielectric flux density exceeds a certain value and this flux concentration lasts for a finite time. It is necessary that the time of application of the stress be finite as any breaking down of a dielectric involves energy which is a time function. This has been well shown by the experiments of Peek*, and others in the study of corona formation, and it has been shown that, under transient voltages, the shorter the time of application of the stress the greater the voltage necessary to produce break down of the dielectric.

Thus the breaking down of porcelain used in the manufacture of high-voltage insulators demands the application of the stress

*A. I. E. E., PROC., Sept. 16, 1915.

Manuscript of this paper was received June 26, 1916.

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for a period of time great enough to permit the accumulation of sufficient energy to destroy enough of the porcelain to puncture the insulator, and the shorter the time of application of the voltage the greater will be the necessary voltage to produce break down.

In a study of insulator failures it will, then, be essential not only to consider the voltage applied to the insulator but also the duration of the voltage. If a transient voltage of very short duration measured in micro-seconds be applied to a dielectric, such as porcelain, of sufficient value to rupture it, with very little power behind it we might expect to find the porcelain punctured, but since the time of the transient is very short the energy involved is small and therefor the destructive effect very local. Thus we might expect to find the porcelain melted over a very small path and solidifying again immediately upon the removal of the transient leaving the insulator in nearly as good condition as it was before the application of the puncturing voltage. However, due to the short duration of the transient voltage and the instant solidifying of the porcelain some impurities would be carried into the porcelain and sealed there, thus weakening, to a certain extent, the dielectric strength of the insulator.

If, however, simultaneously with the application of this transient we should apply a 60-cycle voltage of sufficient value to follow the path which the transient voltage had broken through the insulator, and with sufficient power behind it to keep this path in a molten condition the power arc would be maintained through this path and the insulator destroyed.

Whenever a steady condition of a circuit containing inductance and capacitance is disturbed there is set up an oscillatory transfer of energy from the electromagnetic to the electrostatic fields, or vice versa with a concommittant change in voltage or current conditions or both. The character of the change is dependent upon the relation between the resistance, inductance and capacitance in a manner familiar to all electrical engineers. In a high-voltage transmission line we have the distributed inductance and capacitance of the line and lumped inductance (transformers), and lumped capacitance, (lightning arresters and high-tension transformer windings). These form a circuit that is highly susceptible to oscillations and responds very readily to disturbance of the steady condition. Thus an arcing ground may cause large, relatively low-frequency surges and

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trains of high-frequency waves, the damping of which depends on the resistance of the oscillatory circuit. The frequency of the oscillations in this case will depend on the inductance and capacitance of the oscillating circuit, so on the location of the arcing ground. Thus it will be seen that an arcing ground may produce oscillations of widely varying frequency and varying in damping from well sustained wave trains to abrupt front transient impulses. In the same way a "spill over" of an insulator or the charging of a lightning arrester may subject a line to oscillations of voltage or current or both. The operation of switches especially of the air break type is also often productive of vicious transients.

Since then a great many of the phenomena attendant upon the operation of a modern transmission line involve the superposition upon the sixty-cycle voltage of transients or highly damped high-frequency wave trains, a knowledge of the effects of these transients on the insulators of the line is of great importance and the investigation upon which this paper is based was undertaken to discover if possible the effect of these transients, and from these effects to determine advisable precautions in the manufacture and use of high-voltage insulators.

It has been shown by Ryan*, that the effect of the superposition of a radio-frequency sustained wave train on an audio-frequency wave is to give the combination a striking distance in air equal to the sum of the sparking distances of the two separately. If then we superpose transient voltages upon a normal-frequency wave the stress imposed by the combination will vary between the limits represented by the sum of the maximum transient and maximum 60-cycle voltages and their difference, according to the part of the cycle of the normal frequency wave in which the transient occurs, being the sum if a positive transient coincides with the positive maximum of the sixty cycle wave and the difference if it coincides with the maximum of the negative half wave. At any other point of coincidence the effect would be somewhere between these two limits.

The probability that a transient of known duration will fall within a certain part of a 60-cycle wave if impressed at random on the wave can readily be shown mathematically. Using the part of the positive half of a 60-cycle wave above the effective value it is found that one out of every fifteen million random

*Sustained Radio Frequency High Voltage Discharges, Trans. Inst. Radio Engineers, Sept., 1915.

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impulses each consisting of the positive half of a 750,000-cycle wave will be likely to fall within this interval. If, when this does occur, the summation of the two voltages is sufficient in amount and duration to puncture the insulator the power arc would be very likely to follow the transient, blowing out the melted porcelain before it could solidify, thus permanently puncturing the insulator. It will be readily appreciated however that a transmission line might be operated for several years without this coincidence occurring and further that it might occur very locally and so effect only a few or even single insulators.

Method

An insulator of the type shown in Fig. 1 was selected because of the zone of the flux concentration in the plane at section *A B* and because the dielectric flux concentration near the pin in the inner petticoat was about seven times that near the cap in the outer petticoat. For the purpose of the test the cement can be considered as a perfect conductor and the manufacturers claimed a specific inductive capacity. of 4.8 for this porcelain. Knowing these constants the dielectric field can be drawn to scale and the direction of the lines of force determined as indicated roughly in the figure. This insulator, designated as No. 1, and another of somewhat similar design (No. 2) and a 66,000-volt triple petticoat pin insulator (No. 3) were subjected to a combination of a 60-cycle 50-kv. wave with a transient highly damped and corresponding to one half of a 750,000-cycle wave with a maximum of 30 kv. this transient applied at random with respect to position of coincidence with the 60-cycle wave.

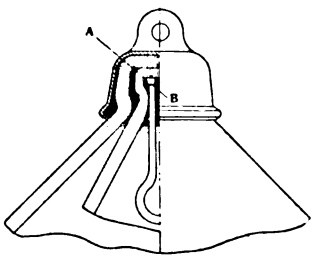

Fig. 1—Type of Insulator Used in Tests

After approximately eight million impulses insulators Nos. 1 and 3 broke down. Insulator No. 2 was then removed but punctured under the attempt to apply dry flash-over voltage, (95,000 volts).

Discussion of Data

Insulator No. 1 was then carefully broken up and examined. The zone *A B* was riddled with fine hair-like lines which under the microscope proved to be tubes of slightly discolored melted porcelain. The discoloration seemed to be due to impurities

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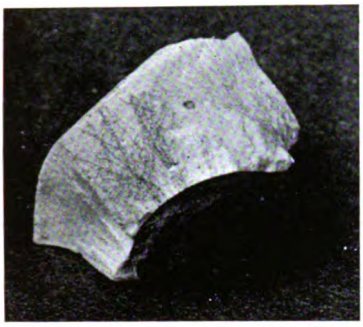
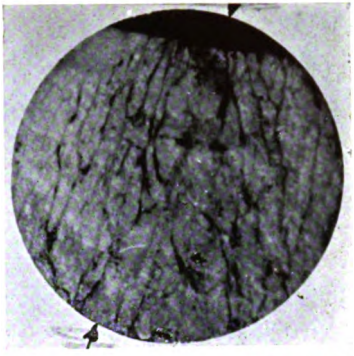


[PEASLEE]

FIG. 2—FRACTURES FROM ZONE A-B INSULATOR NO. 1. TWO AND ONE-HALF DIAMETERS — INNER PETTICOAT



[PEASLEE]

FIG. 4—TEN DIAMETERS

[PEASLEE]

FIG. 3—POWER ARC PUNCTURES OUTER PETTICOAT INSULATOR NO. 1—TWO AND ONE-HALF DIAMETERS

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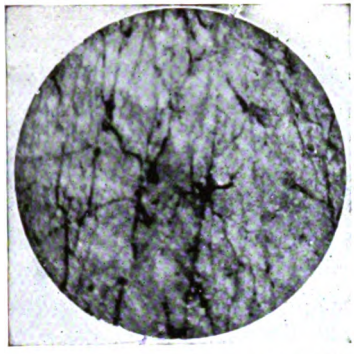

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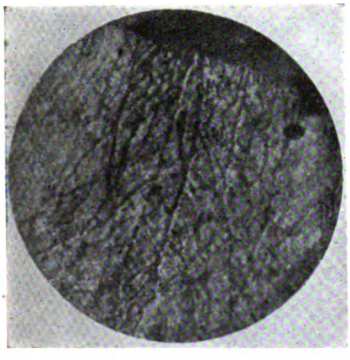
FIG. 5—TEN DIAMETERS

[PEASLEE]

FIG. 6—TEN DIAMETERS



[PEASLEE]

FIG. 7—TEN DIAMETERS

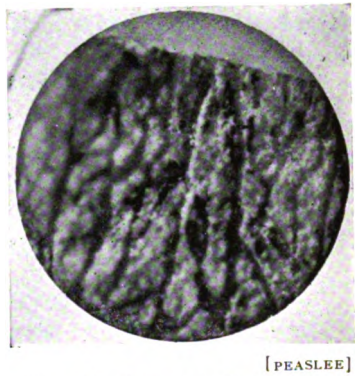


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FIG. 8—TWENTY DIAMETERS

[PEASLEE]

FIG. 9—FORTY DIAMETERS

[PEASLEE]

FIG. 10—TEN DIAMETERS

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carried into the porcelain by the puncturing arc and sealed into the tube of melted silica. The appearance of this puncture was very different from that caused by the power arc as shown in Fig. 3, and it is very significant that while these fine punctures were very numerous in the zone *A B* in the inner petticoat, there were practically none in the outer petticoat, and what few were found were not appreciably discolored. Also the inner petticoat fractured in which might almost be called a cleavage plane along this zone of flux and puncture concentration, showing that the porcelain had been weakened mechanically as well as electrically by these break downs even though they had sealed up in time to prevent the formation of a power arc.

Fig. 2 shows a surface fractured from zone *A B* magnified two and one-half diameters showing the fine cross lines, each a tube of melted silica, representing a puncture by a transient that has sealed up preventing the formation of a power arc. This sample is taken from the inner petticoat.

Fig. 3 is from a photograph of the outer petticoat of this insulator magnified two and one-half diameters showing the two power punctures that occurred in it when the inner petticoat, weakened by these impacts, finally ruptured. This photograph shows very clearly the marked difference between the puncture produced by a transient voltage only and one followed by a power arc.

Microscopic studies of these samples were extremely valuable and reveal many interesting features that the pictures cannot show regarding the mechanism of the break down etc.

Referring to the micro-photographs, Fig. 4 is taken from the inner petticoat in zone *A B* of insulator No. 1 showing the radiating punctures from the edge of the specimen nearest the pin. The broad white streak between the arrow points is the path of the power arc that finally, striking through this weakened zone, punctured and destroyed the insulator.

Fig. 5 shows a portion of the same specimen taken along the path of the power arc further towards the outside of the inner petticoat. The tendency of the transient voltages to jump across between defects in the dielectric is very noticeable here, and Fig. 6, taken from insulator No. 1, shows this very well, as seven distinct and separate punctures may be seen striking through this air hole. As this is magnified ten diameters the size of the defect can be appreciated and also the care necessary in the manufacture of the porcelain to produce a product free from defects that will weaken the insulator.

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Figs. 7, 8, and 9 are taken from the same specimen from insulator No. 2 but magnified to different diameters as indicated.

Fig. 10 is taken from insulator No. 3, and shows very well the tendency of the transient to seek out and follow a series of defects in the porcelain. Fig. 11 is also taken from insulator No. 3.

Fig. 12 is taken from the inner petticoat of insulator No. 2 and shows very clearly the path of the power arc as well as the paths of the transients.

Further Investigations

It would seem from a consideration of the fundamental mechanism of dielectric break down that two things must be avoided to prevent damage to an insulation; a concentration of dielectric flux above a certain value and a finite duration of this concentration. This seems well borne out by the data secured, as the failures shown in the photographs occurred in the zone indicated by this theory, and as was expected, were

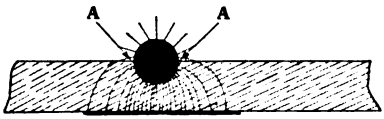

Fig. 13

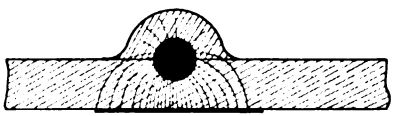

Fig. 14

almost entirely confined to the inner petticoat of each insulator. As a further investigation a piece of grooved porcelain was secured and a conductor placed in this groove with a plate against the other side of the porcelain opposite the groove. The resulting flux distribution is roughly indicated in Fig. 13. However it was feared that the corona forming on this conductor would act as a relief valve for the impact of the transient, the dielectrically weaker air absorbing the shock and so protecting the porcelain. Therefor a second sample was prepared as shown in Fig. 14 and the conductor covered with paraffin, the covering extending well up on the connection to the conductor to the point where the separation of the plate and conductor would prevent the formation of corona, thus forcing the impact onto the porcelain.

A third sample was prepared with a needle placed with its point against one side of a piece of porcelain, the whole needle being imbedded in sealing wax, while a plate was placed on the other side of the test piece.

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FIG. 11—TEN DIAMETERS

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FIG. 12—TEN DIAMETERS

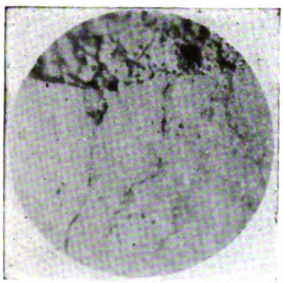

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FIG. 15—FIVE DIAMETERS

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FIG. 16—FIVE DIAMETERS

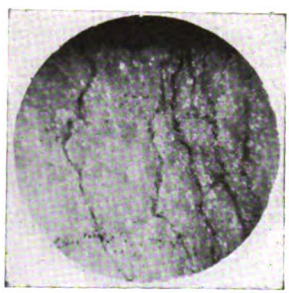

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FIG. 17—FIVE DIAMETERS

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These samples were subjected to the impact tests previously described, except that in this test the transients corresponded to a half of a 460,000-cycle wave, for about 70 hours with approximately 120 impacts per second. At the end of that period the samples shown in Figs. 13 and 14 were broken along the bottom of the grooves and the other under the needle point.

The sample arranged as in Fig. 13 showed no traces of puncture, while the one shown in Fig. 14 was liberally sprinkled along the bottom of the groove with the characteristic transient puncture. In none of these test pieces did the power arc follow through as the 60-cycle voltage was purposely kept low.

Fig. 15 shows the puncture found in the bottom of the groove in test piece shown in Fig. 14, and Fig. 16 shows the puncture found under the needle point. It should be noted that in this specimen the thickness of porcelain between the needle point and plate was twice that between the conductor and plate in Figs. 13 and 14.

Fig. 17 is included as of interest in showing the manner in which the transients strike into the porcelain from irregularities in the surface of the porcelain or cavities in the cement.

Conclusion

From what is now known of the action of high voltages of normal and high-frequency sustained waves and of transient duration it is apparent that the successful insulator for continued service in high voltage transmission lines must be designed with the following points in mind.

1. The actual puncture voltage of the insulator divided by the safety factor desired must be above the sum of the normal frequency maximum voltage that will be encountered in operation, (taking due account of relatively low frequency surges), and the maximum transient or sustained high-frequency voltage that may be impressed on the line. If this is not done the insulator will in time be weakened by the impact of these transient voltages and ultimately must fail.

2. Points or zones of excessive flux concentration must be avoided. A careful porportioning must be undertaken to avoid the extreme dielectric field distortion and concentration commonly met with in insulators now on the market. Ratios of flux density in different parts of the field of eleven to one have been noted in certain insulators and these have almost universally given trouble in time on high-voltage lines.

3. The porcelain must be free from air bubbles and defects

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and this is a problem that must be met by the ceramic engineer before it is possible to manufacture reliable insulators.

4. The insulators should have a puncture voltage as many times the dry flash over voltage as the desired safety factor. The importance of this point is not always realized but when it is remembered that there is a large time lag in the break down of air it will be realized that severe impact stresses can be placed on an insulator by transients. With a sufficiently abrupt transient, a voltage of much more than flash-over may be impressed on an insulator in air and this is in the form of an impact delivered inside the insulator, weakening it at every application.

5. To avoid placing dielectrics of different dielectric constants in series the surface of the insulator should follow, in so far as possible, the lines of force of the dielectric field.

6. Caps and metal parts should be smooth and of large radii of curvature to make the corona forming voltage as high as possible. It is possible to design an insulator that will flash over after the manner of sphere gap break down without the formation of corona.

7. The design should be such mechanically as to keep the lines or zones of mechanical stress removed from the lines of electrical stress, and where this is impossible the two stresses should be as nearly as possible at right angles. This point has been brought out by recent study of the influence of the line of action of mechanical stress in porcelain upon the path of the resulting fracture.

These investigations were carried out in the high-tension laboratory of Oregon Agricultural College and the writer takes this opportunity to express his appreciation of the assistance of Mr. C. E. Oakes and Mr. Winfield Eckley who assisted him in the test, and Prof. S. H. Graf of the Department of Experimental Engineering by whose courtesy the micro-photographs were made possible. Grateful acknowledgment is also made to Mr. L. T. Merwin for his very valuable suggestions in constructive criticism of the manuscript.

It is not felt that the data here presented brings out any previously unknown phenomena as this action has long been suspected by or known to many of the workers in this field, but it is presented as the preliminary results of an extensive investigation now in progress on the subject and it is hoped that a study of these photographs will increase the respect of the engineers, who are designing and using insulators, for the destructive ability of transient voltages.

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To be presented at the Pacific Coast Convention of the American Institute of Electrical Engineers, Seattle, Wash., September 5-9, 1916.

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AN ARTIFICIAL TRANSMISSION LINE WITH ADJUSTABLE LINE CONSTANTS

BY C. EDWARD MAGNUSSON AND S. R. BURBANK

ABSTRACT OF PAPER

A description is given of an artificial transmission line which can be readily adjusted to represent 200 miles (321.86 km.) of commercial transmission lines of any spacing up to a maximum of 120 in. (3 m.) and any size wire up to 4/0 copper. It can also be made to correspond to aerial or cable telephone lines and to power cables. The use of this type of line in laboratory courses on transmission line phenomena is illustrated by a number of typical experiments. It is shown that quantitative data, sufficiently accurate for instructional purposes, may be obtained by using portable voltmeters and ammeters and by the oscillograph.

THAT artificial transmission lines can be used to advantage in investigations on transmission line phenomena is well known. It has been proved by extended research* that actual transmission line phenomena can be accurately reproduced in laboratory structures and that the theoretical equations correctly express the quantitative relations between the line constants, voltages, currents, time and space phase angles and other factors that enter in the general transmission line problem. Artificial transmission lines have, however, been used only to a very limited extent either as laboratory apparatus for experimental work by students in power transmission courses, or by engineers when investigating industrial transmission systems. Very few engineering colleges have any facilities for laboratory work on transmission lines. The instruction is given by lectures, text-book recitations and class-room problems, without the aid of quantitative laboratory experiments. As a consequence comparatively few students gain a clear insight into transmission line phenomena, and although they may be able to develop the standard equations they fail to comprehend the physical phenomena involved or to understand what actually takes place in the transmission system. That quantitative laboratory experi-

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*See Bibliography on page 1257.

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ments would be as desirable in the study of transmission lines as the customary experimental work in courses on alternators, motors or telephones is admitted. The difference in practise has been due chiefly to a lack of suitable apparatus for giving laboratory instruction on transmission lines.

The purpose of this paper is to describe the design and construction of an artificial transmission line adapted to the requirements of laboratory apparatus for undergraduate instructional experiments as well as for research, and to report a few typical experiments. The line has been in successful operation for the past three years in the Electrical Engineering Laboratories of the University of Washington. It consists of twenty units connected in series as shown in Fig. 1. Each unit, Fig. 2, is complete in itself and represents approximately ten miles of a power transmission line. The line can readily be adjusted, within wide limits, to any spacing or size of wire, or converted into a standard telephone line. The wiring diagram for the units is shown in Fig. 3 and for the complete line of twenty units in Fig. 4. The apparatus represents one line to neutral and can therefor be used in experiments on either single-phase or polyphase systems. The diagram shows that the line is of the " lumpy " type, similar to the artificial line at Harvard University,* with the condensers connected at the middle point of the inductance in each unit. While lines with uniformly distributed† inductance, condensance and resistance comply strictly with actual transmission line conditions the first cost and maintenance are much greater than for the "lumpy" type. Moreover the latter type can be made adjustable so as to represent

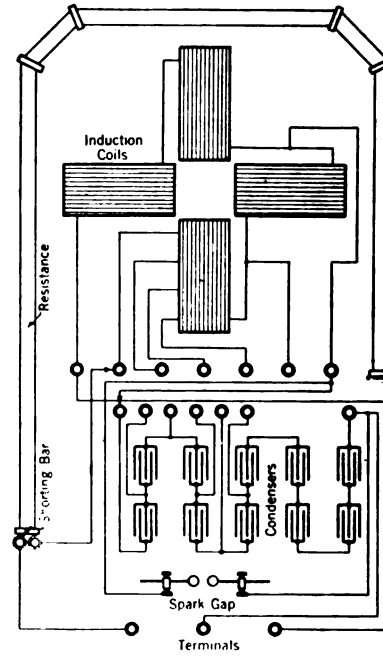

FIG. 3—WIRING DIAGRAM OF EACH UNIT

*See bibliography Numbers 5, 6, 7, and 8.

†See Bibliography Numbers 2 and 3.

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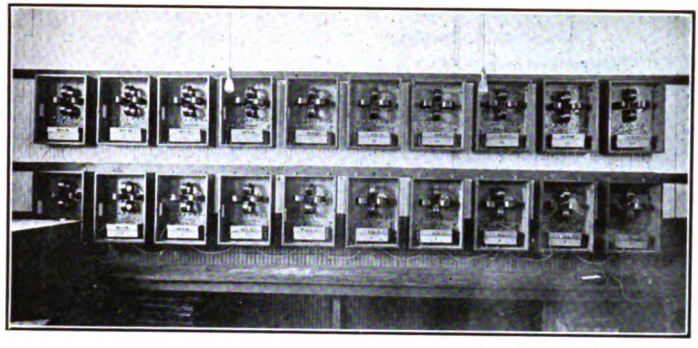
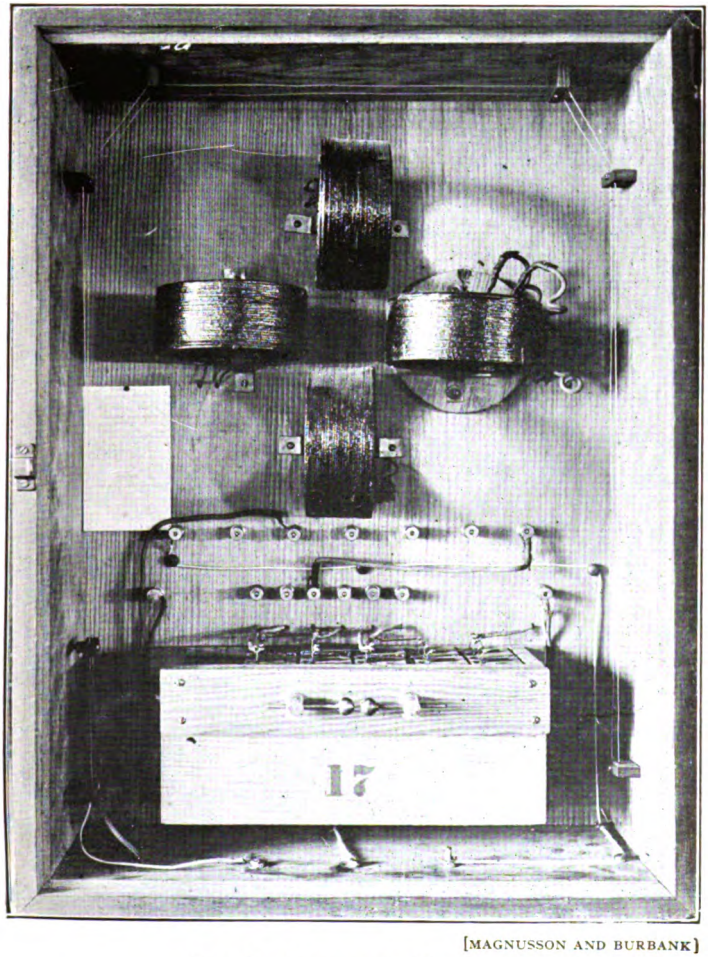


[MAGNUSSON AND BURBANK]

FIG. 1—COMPLETE LINE OF TWENTY UNITS



[MAGNUSSON AND BURBANK]

FIG. 2—ASSEMBLED UNIT

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lines of almost any size of wire and for different spacings. The spark-gap on each unit can be adjusted so as to provide protection to the condensers against excessive voltages that may develop under resonance conditions. The ten mile unit was selected as a sufficiently close approximation to the uniformly distributed line constants of industrial transmission lines for frequencies up to 800 cycles per second.

Both for instructional and research purposes it is desirable to have an apparatus that can be adjusted so as to represent lines differing, not merely in length, but also in size and spacing of the conductors. This line is so designed that it can readily be adjusted so as to correspond to a line of any spacing up to 120 in. (305 cm.) and for any size of wire up to No. 4/0 hard-drawn copper. By the insertion of a 50-ohm non-inductive resistance between each unit it is converted into a telephone line of practically standard specifications.

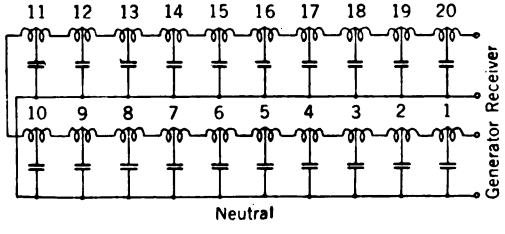

FIG. 4—WIRING DIAGRAM OF COMPLETE LINE

To comply with the above requirements the line constants must be adjustable within the following limits:

Resistance, minimum value = 2.59 ohms.

Inductance, maximum value = 0.021 henry;

Condensance,..... = from 0.1 to 1.0 microfarad

Resistance. The resistance of the inductance coils must not exceed minimum resistance in the unit, each of the four coils must be equal to or less than 2.59 ÷ 4 = 0.65 ohm. Selecting No. 14 A. W. G., d. c. c., copper, the length of wire in each coil must not exceed 257 ft. (78.3 m.). The coils as constructed* have 250 ft. each, thus allowing for the resistance of the connecting wires and for a slight adjustment when the line represents No. 4/0 copper wire. For lines with smaller sized conductors the additional resistance is obtained by moving the short-circuiting clamp on the loop of "Advance" resistance wire. Figs. 2 and 3.

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Inductance. The inductance is obtained from four short air-core solenoids arranged in a square. For a given length of wire the inductance depends on the dimensions of the coil. The required dimensions were obtained by means of Brooks Formula†. The final dimensions of the coils as constructed are:

Mean radius	2.20 inches	(5.59 cm.)
Length of coil	2.15 "	(5.47 cm.)
Thickness of winding	0.60 "	(1.52 cm.)
Length of wire	250. feet	(76.3 m.)
Number of turns (eight layers of twenty-seven turns each)	216.	

The mutual inductance is very nearly 8 per cent of the self-inductance for each unit. With the coils in position the measured value corresponds to the amount required.

The inductance in each unit can be varied by turning the right hand coil and by using the taps on the lower coil. Any induct-

TABLE I.

Unit No. 15.

Position of movable coil	Coils in Series					
	4	3¾	3½	3¼	3	2
0°	0.0214	0.0193	0.0176	0.0161	0.0154	0.0098
45°	0.0209	0.0186	0.0167	0.0156	.....	.....
90°	0.0199	0.0178	0.0160	0.0149	.....	.....
135°	0.0188	0.0171	0.0158	0.0145	.....	.....
180°	0.0185	0.0168	0.0152	0.0142	.....	.....

ance up to the maximum value can be obtained by making the proper adjustments. All the units have been calibrated showing the inductance for five positions of the movable coil and for four taps on the lower coil as illustrated in Table 1.

The average maximum inductance for the whole line is 0.0213 henry for each unit. The measured inductance for the several units varies from 0.021 to 0.022 except for unit No. 2 which is 0.0197 henry.

Condensance. The line condensance is obtained from 200 standard telephone condensers, type No. 21-AA, guaranteed to stand 1000 volts. Each unit has ten condensers connected in series with taps brought out at the terminals of the 5th, 6th, 7th, 8th, 9th, and 10th condenser. Each unit has been calibrated and the results tabulated as illustrated by Table 2.

*Bibliography No. 11.

†University of Illinois, Bulletin No. 53.

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A spark-gap was connected across the condensers as a protection against voltages in excess of the rated value of 1000 volts per condenser. Under resonance conditions this protection is necessary.

Cost. The cost per unit was approximately $24.00, or a total of $480.00 for the complete line of twenty units.

Instruments. For accurate measurements an a-c. potentio-

TABLE II.
Unit No 15.

	Number of condensers in series.					
	5	6	7	8	9	10
Microfarads	0.182	0.151	0.131	0.114	0.102	0.092

meter is necessary and an instrument like the Drysdale-Tinsley alternating and continuous current potentiometer gives excellent results. Unfortunately the potentiometer is expensive and requires more skill in the operator than can be expected from ordinary students in power transmission courses. Quantitative values, sufficiently accurate for instructional purposes, may be obtained by means of ordinary portable voltmeters and ammeters,

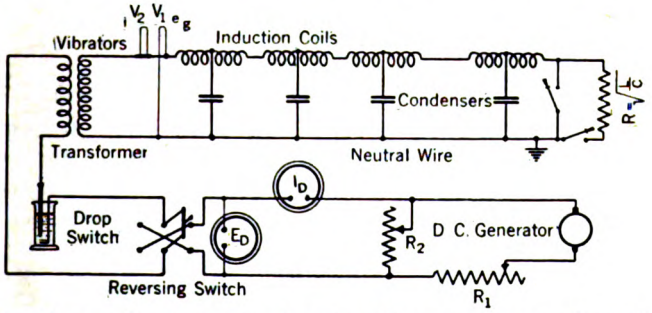

FIG. 5—WIRING DIAGRAM FOR IMPULSE OSCILLOGRAMS IN FIGS. 6, 7, 8, 9, 10, 11

for numerous experiments, as may be seen by comparing the calculated and the observed values in several of the experiments described in this paper. The instruments used were Standard voltmeters, ammeters, speed indicators, and a three-element oscillograph.

Great care must be exercised in keeping the frequency constant throughout each test. Slight changes in frequency will

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cause considerable changes in the voltmeter and ammeter readings.

Typical Experiments. The experimental data have been selected from student's laboratory reports, and credit is due Mr. R. Rader for Figs. 6, 7 and 8; Messrs. G. S. Palmer and D. K. Chaudhuri for Figs. 13 to 18 and 20 to 27; and Messrs. S. R. Burbank and F. T. Yamada for Figs. 9 to 11 and 28 to 37.

The circuit connections are shown in Figs. 5, 12 and 19 for each experiment. The oscillograms and the drawn curves are in a large measure self-explanatory. In all cases the size of wire was equivalent to No. 4/0 hard-drawn copper. The spacing was either 96 in. or 120 in. (2.4 or 3 m.) as noted below each figure. Experiments with other spacings and for other sizes of wire gave similar results.

The experiments selected may be grouped into three divisions:

1. Sudden impulses impressed on the line.

2. Voltage and current readings along the line. Constant voltage at the generator end and constant frequency.

3. Resonance.

Group 1

A direct-current generator was connected to the primary of a transformer and the line to the secondary. Between the generator and the transformer was a drop switch, Fig. 5. Upon closing the switch a sudden impulse was impressed on the line from the secondary winding of the transformer.

For Figs. 6, 7 and 8 the line constants were $R = 51.7$ ohms, $L = 0.427$ henry, $C = 2.92$ microfarads. The original voltage and current impulses with the reflections are shown for receiver end open in Fig. 6 and short circuited in Fig. 7. No reflections appear in Fig. 8 when the receiver has a resistance equal to

$$\sqrt{\frac{L}{C}} \text{ ohms.}$$

Calculating the length of the line from the line constants it should be equivalent to 208 miles (334.7 km.). Measuring the time taken for the impulse to be reflected from the receiver end as in Fig. 7, and assuming a velocity of 3×10^{10} cm. per second, the equivalent length of line was 214 miles (334.4 km.). A number of trials gave a similar discrepancy of approximately 3 per cent. In the fall of 1916 the condensers, a cheap grade, were replaced by Type 21-AA condensers. Measurements on

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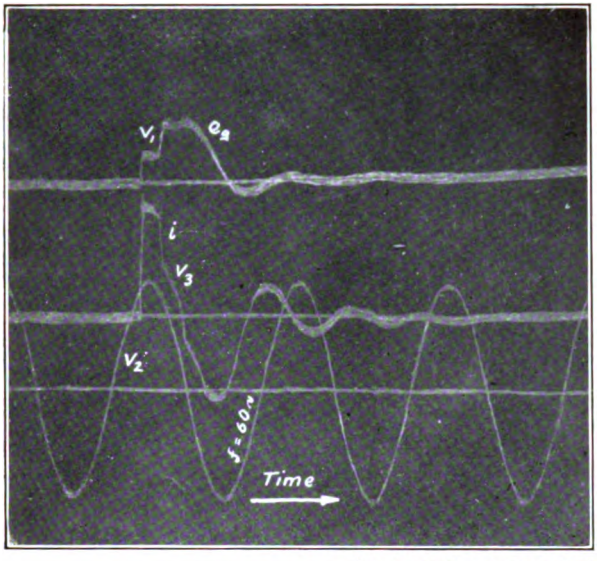
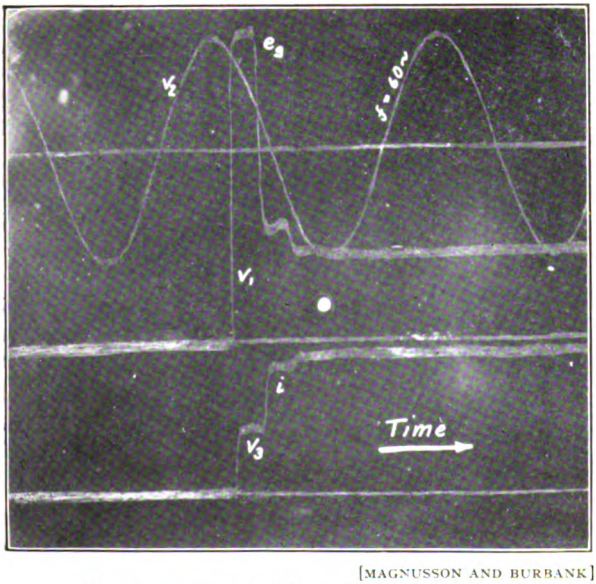


[MAGNUSSON AND BURBANK]

FIG. 6—RECEIVER END OPEN

Spacing 120 in. $-E_D = 98$ v. $-I_D = 6.00$ amp.



[MAGNUSSON AND BURBANK]

FIG. 7—RECEIVER END SHORT CIRCUITED

Spacing 120 in. $-E_D = 100$ v. $-I_D = 2.5$ amp.

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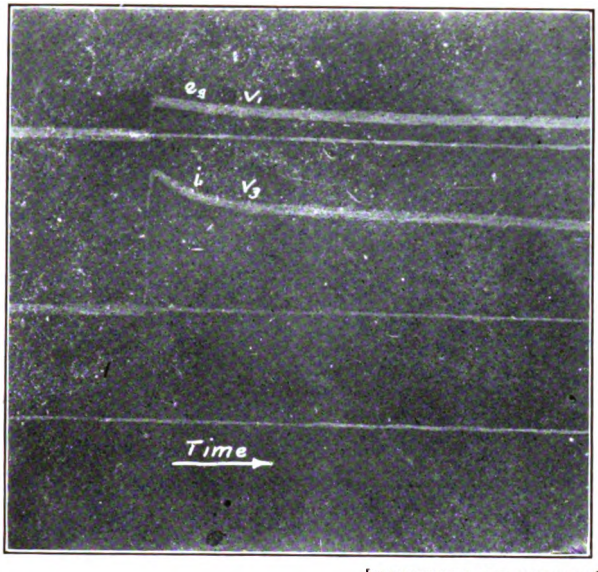
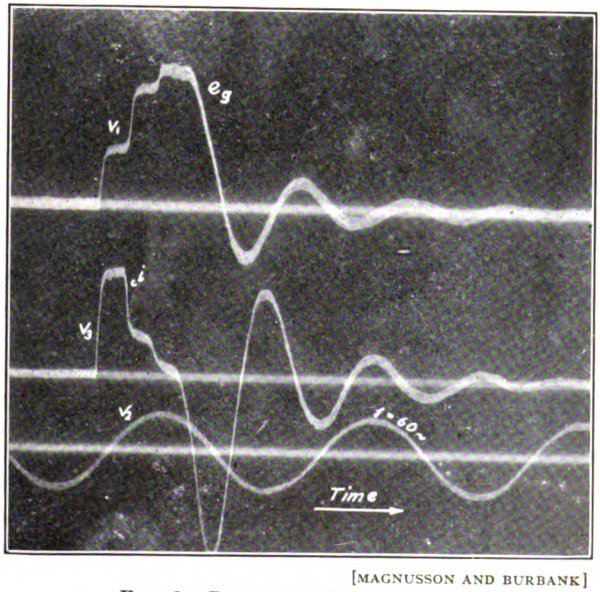


[MAGNUSSON AND BURBANK]

FIG. 8—RECEIVER END CLOSED THROUGH $\sqrt{\frac{L}{C}}$ OHMS

Spacing = 120 in. – E_D = 104 v. – I_D = 2.3 amp.



[MAGNUSSON AND BURBANK]

FIG. 9—RECEIVER END OPEN

Spacing = 96 in. – E_D = 110 v. – I_D = 19.8 amp.

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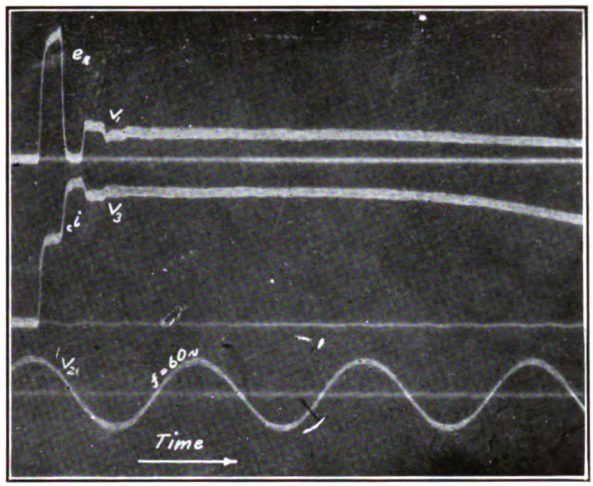
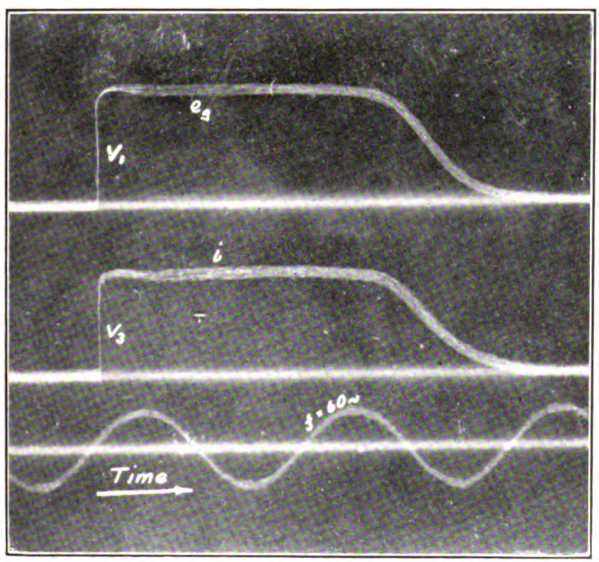


[MAGNUSSON AND BURBANK]

FIG. 10—RECEIVER END SHORT CIRCUITED

Spacing = 96 in. – E_D = 101 v. – I_D = 20.0 amp.



[MAGNUSSON AND BURBANK]

FIG. 11—RECEIVER END CLOSED THROUGH $\sqrt{\frac{L}{C}}$ OHMS

Spacing = 96 in. – E_D = 110 v. – I_D = 19.7 amp.

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oscillograms taken after the new type of condensers were on the line, as in Figs. 9 and 10, checked more closely with the length calculated from the line constants. Thus for Figs. 9, 10 and 11 the line was adjusted for a spacing of 96 in. (2.4 m.) The line constants were $R = 52.9$ ohms; $L = 0.412$ henry; $C = 3.03$

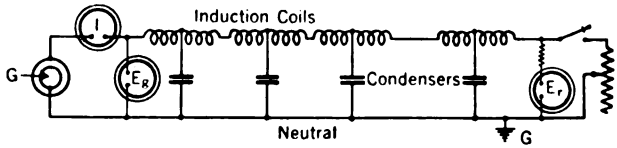

FIG. 12—WIRING DIAGRAM FOR LINE CHARACTERISTICS, FIGS. 13, 14, 15, 16, 17, 18—AND RESONANCE CURVES FIGS. 28 AND 33

microfarads. From the line constants the equivalent length of line was 208.5 miles (335.5 km.) From measurements on the oscillogram in Fig. 9 the equivalent length was 206.5 miles (332.3 km.) and from the oscillogram in Fig. 10, 208 miles (334.7 km.) A slight leakage in the first set of condensers probably caused the retardation of the electromagnetic wave. After

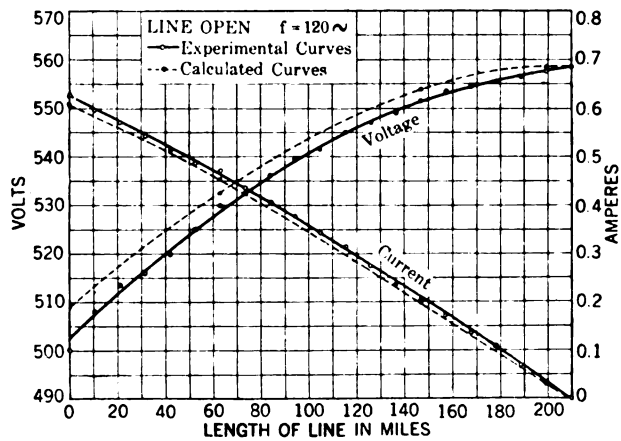

FIG. 13—VOLTAGE AND CURRENT CHARACTERISTICS

three reflections in the open line, (Figs. 6 and 9) the transformer and the line oscillate together causing an oscillatory transient of lower frequency.

GROUP 2

The change in the magnitude of the voltage and current along the line is shown in Figs. 13 to 18, inclusive, for the line open and

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for frequencies of 60, 100 and 120 cycles, respectively, in Figs. 13, 15 and 17, and similarly for the line loaded so as to have generator and receiver voltages each equal to 500 volts, in Figs. 14, 16 and 18.

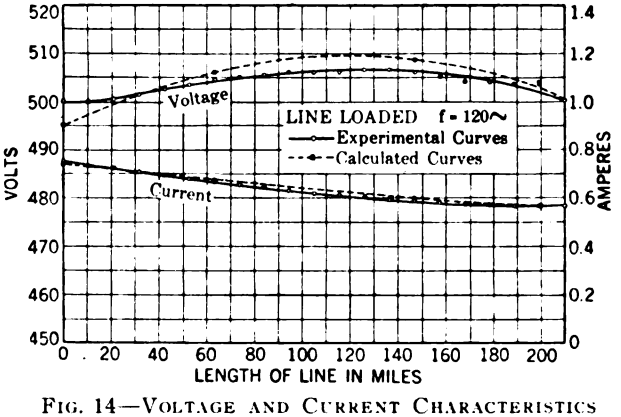

FIG. 14—VOLTAGE AND CURRENT CHARACTERISTICS

Necessarily the shunting of the voltmeter across the line changed the conditions in each case and caused discrepancies in the curves as indicated by the difference between the drawn and broken lines. Extreme care had to be exercised in keeping

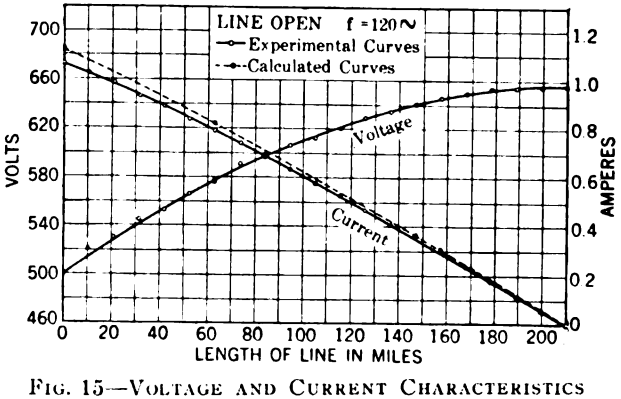

FIG. 15—VOLTAGE AND CURRENT CHARACTERISTICS

the frequency constant for each set of readings. A slight change in frequency will cause a considerable change in the receiver voltage with the line open. This is readily seen by comparing the receiver voltages for 60, 100 and 120 cycles in Figs. 13, 15 and 17.

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GROUP 3

In obtaining the data on resonance, two single-phase alternators were used. Alternator A gave a voltage wave which appeared to be simple harmonic but on analysis was found to

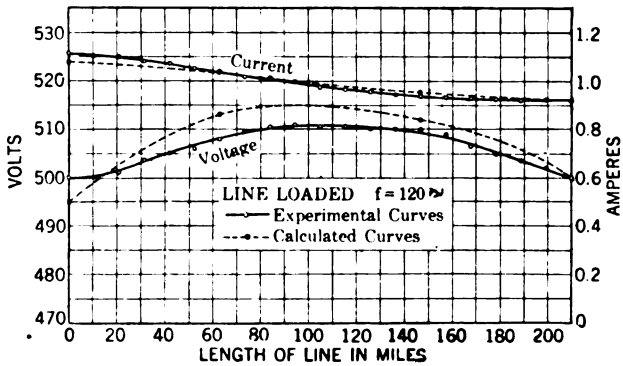

FIG. 16—VOLTAGE AND CURRENT CHARACTERISTICS

have a small third harmonic, about one per cent, of the fundamental. The shape of the voltage wave of alternator B is shown in Fig. 32, consisting of a fundamental combined with a 28.2 per cent third harmonic and a 5.4 per cent fifth harmonic. The

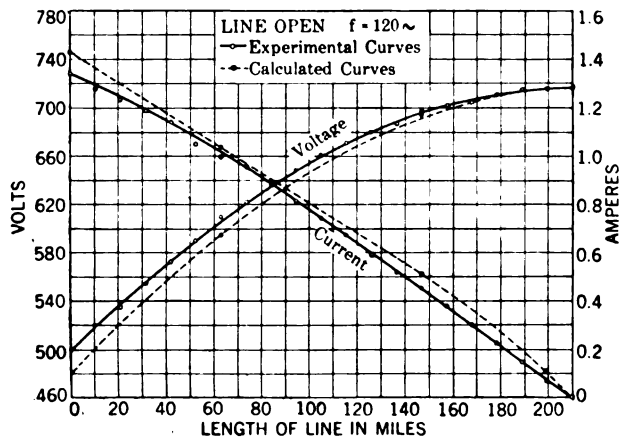

FIG. 17—VOLTAGE AND CURRENT CHARACTERISTICS

frequency of alternator A was normally 137 cycles and for B, 60 cycles.

At first it was assumed that alternator A gave a simple sine wave. The first indications that the assumption was not true

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were difficulties in securing consistent readings at all frequencies, particularly between 70 and 75 cycles. With the generator voltage of 1000 volts and the frequency about 72 cycles, the condensers in unit No. 20, at the receiver end, were punctured. Upon investigation it was found that the third harmonic caused resonance in the line and that the receiver voltage was greatly

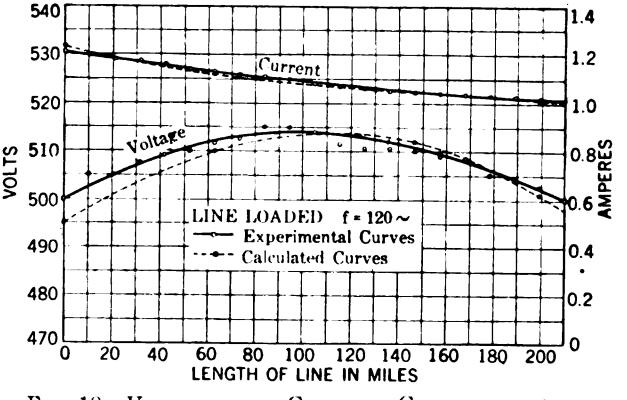

FIG. 18—VOLTAGE AND CURRENT CHARACTERISTICS

in excess of what would be produced by the fundamental. To prevent a similar accident spark-gaps were placed in each unit as shown in Figs. 2 and 3.

To secure accurate readings on resonance values, an a-c. potentiometer is necessary, but the effect may be observed on ordinary oscillograms and to some extent measured by portable voltmeters.

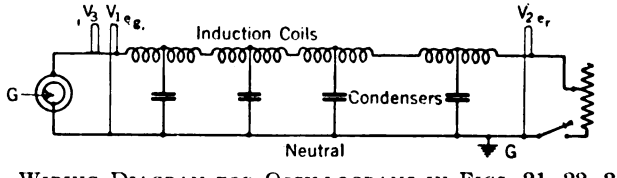

FIG. 19—WIRING DIAGRAM FOR OSCILLOGRAMS IN FIGS. 21, 22, 23, 24, 25, 26, 27, 29, 30, 31, 34, 35, 36, 37

In Figs. 20 to 24, inclusive, are shown the oscillograms of the generator and receiver voltages and the charging current for 60, 66, 72, 100 and 120 cycles using alternator *A*. The generator voltage is nearly a sine wave in all cases. The receiver voltage and the charging current show a third harmonic in Fig. 20; an increased distortion in Fig. 21 and a maximum third harmonic

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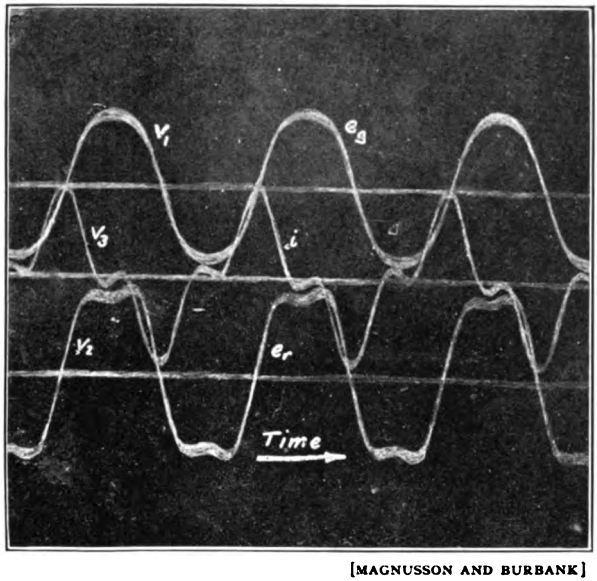
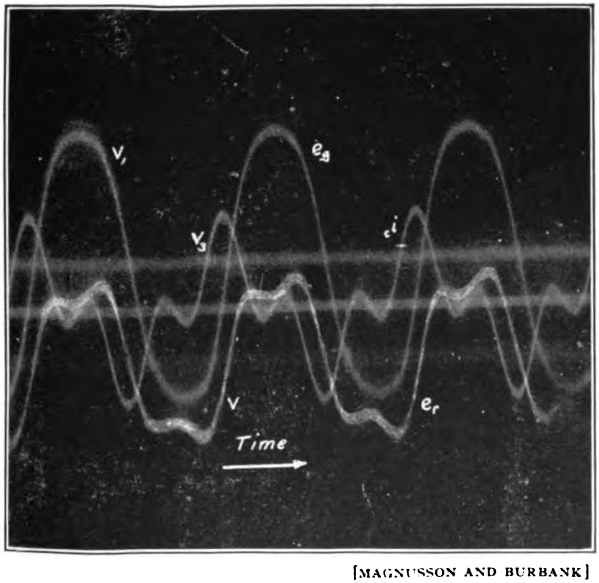


[MAGNUSSON AND BURBANK]

FIG. 20—RECEIVER END OPEN

Spacing = 120 in. — f = 60 ~ — L = 0.427 h. — C = 2.96 mf. — E_g = 500 v. — E_r = 558 v — I = 0.63 amp.



[MAGNUSSON AND BURBANK]

FIG. 21—RECEIVER END OPEN

Spacing = 120 in. — f = 60 ~ — L = 0.427h. — C = 2.96 mf. — E_g = 500 v.

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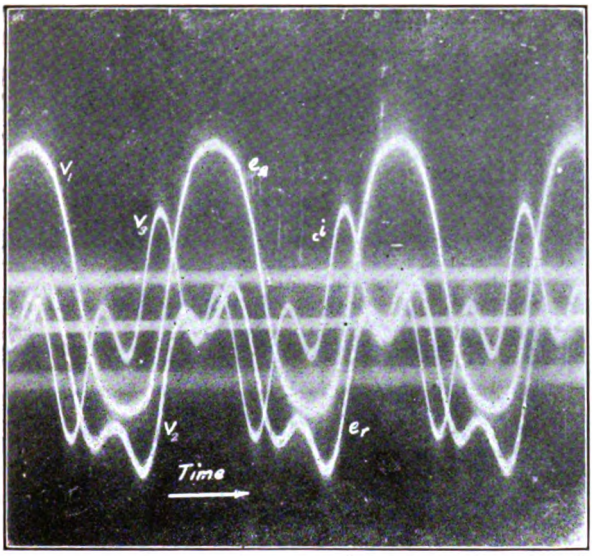
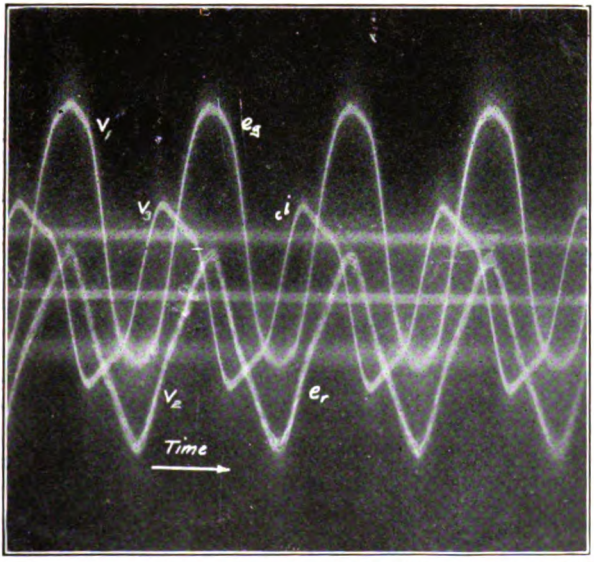


[MAGNUSSON AND BURBANK]

FIG. 22—RECEIVER END OPEN

Spacing = 120 in. – f = 72 ~ – L = 0.427h. – C = 2.96 mf. – E_g = 500 v.



[MAGNUSSON AND BURBANK]

FIG. 23—RECEIVER END OPEN

Spacing 120 in. – f = 100 ~ – L = 0.427 h. – C = 2.96 mf. – E_g = 500 v. – E_r = 655 v. – I = 1.06 amp.

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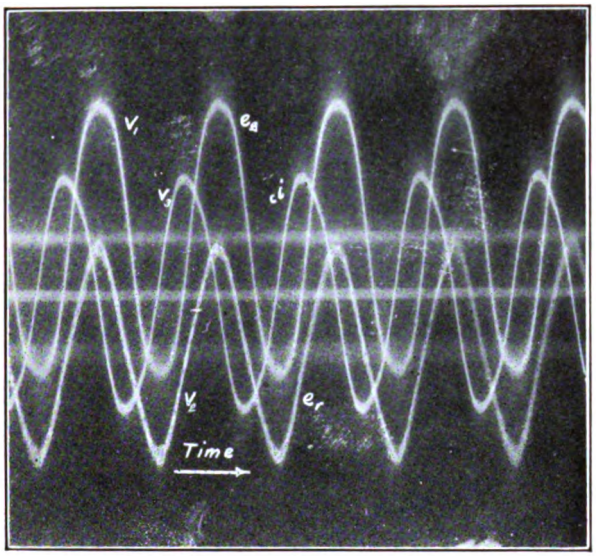
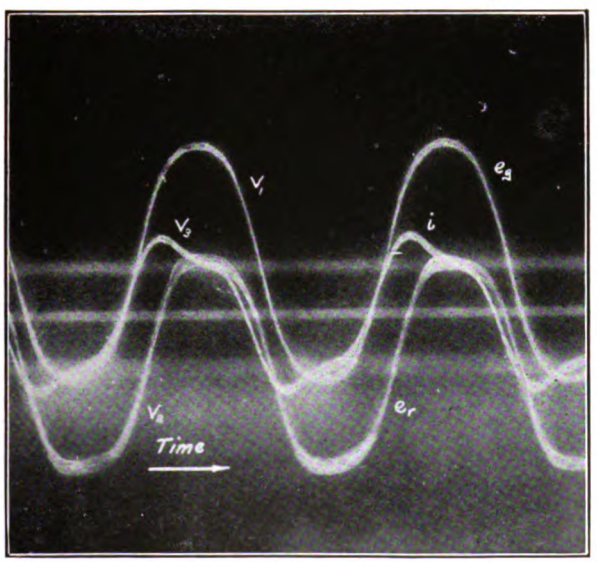


[MAGNUSSON AND BURBANK]

FIG. 24—RECEIVER END OPEN

Spacing 120 in. — f = 120 ~ — C = 2.96 mf. — L = 0.427 h. — E_g = 500 v. — E_r = 716 v. — I = 1.34 amp.



[MAGNUSSON AND BURBANK]

FIG. 25—RECEIVER END LOADED

I_r — 0.56 amp. — Spacing 120 in. — f = 60 ~ — C = 2.96 mf. — L = 0.427 h — E_g — 500 v — E_r = 500 v. — I = 0.75 amp.

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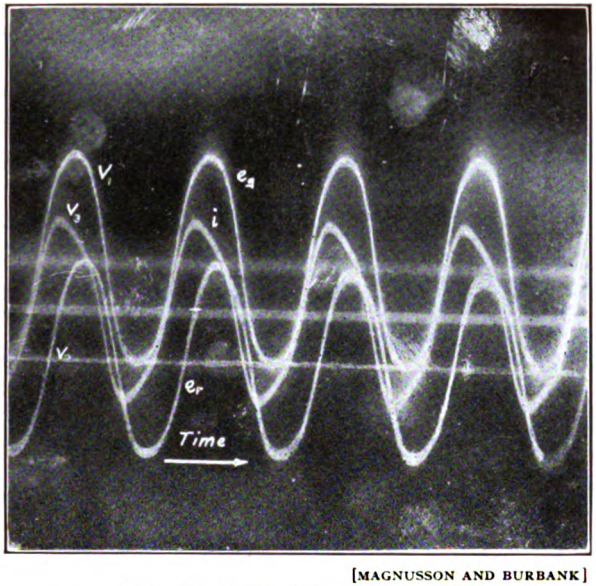
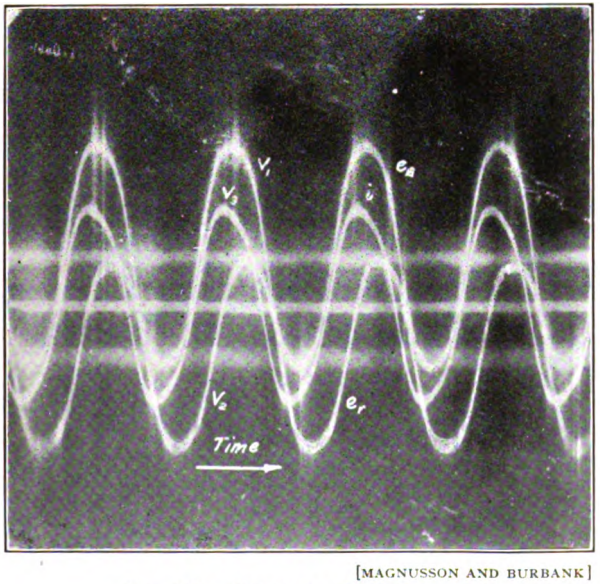


[MAGNUSSON AND BURBANK]

FIG. 26—RECEIVER END LOADED

I_r = 0.92 amp. — Spacing 120 in. — f = 100 ~ — C = 2.96 mf. — L = 0.427 h. — E_g = 500 v. — E_r = 500 v. — I = 1.12 amp.



[MAGNUSSON AND BURBANK]

FIG. 27—RECEIVER END LOADED

Spacing 120 in. — f = 120 ~ — I_r = 1.01 amp. — L = 0.427 h. — C = 2.96 mf. — Eg = 500 v. — E_r = 500 v. — I = 1.21 amp.

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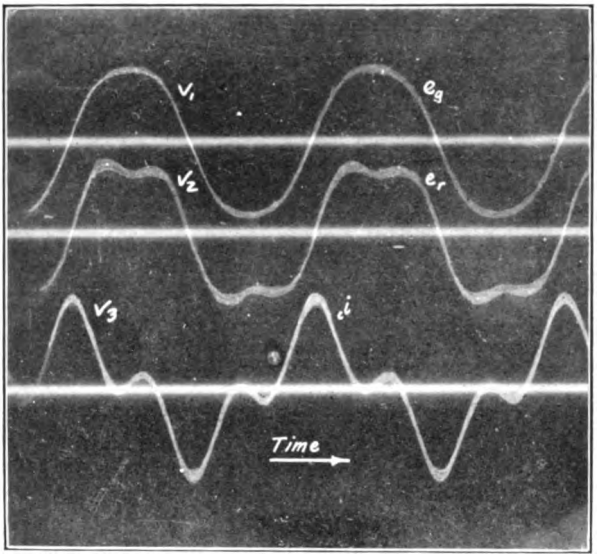
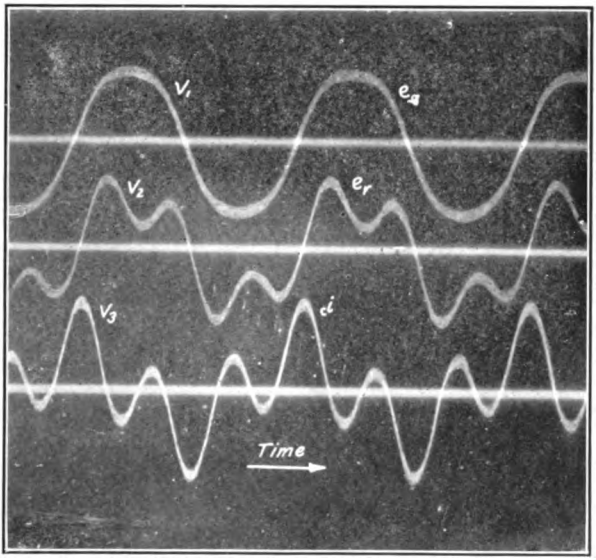


[MAGNUSSON AND BURBANK]

FIG. 29—RECEIVER END OPEN

Spacing = 96 in. – f = 60 ~ – C = 303 mf. – L = 0.412 h. – E_g = 500 v. – E_r = 570 v. – I = 0.70 amp.



[MAGNUSSON AND BURBANK]

FIG. 30—RECEIVER END OPEN

Spacing = 96 in. – f = 74 ~ – C = 3.03 mf. – L = 04.12 h. – E_g = 500 v. – E_r = 690 v. – I = 1.35 amp.

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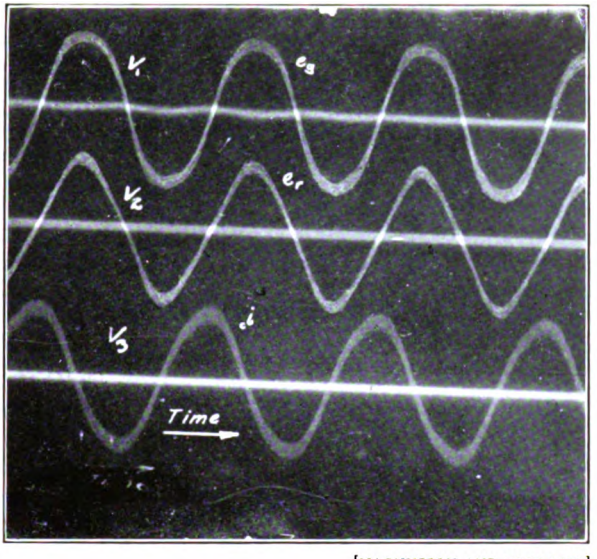
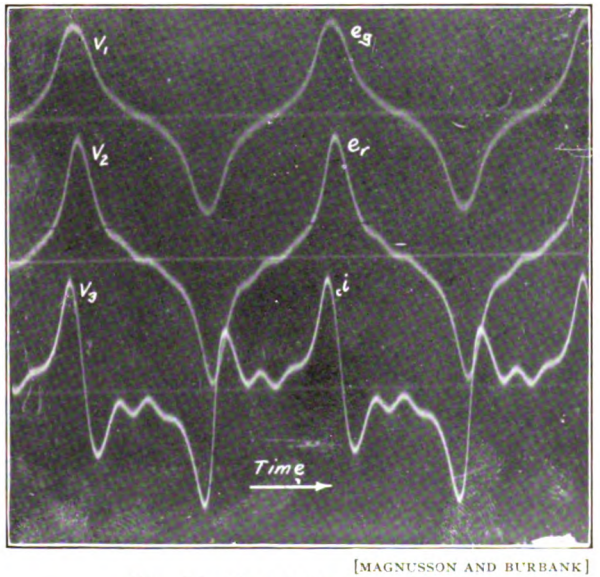


[MAGNUSSON AND BURBANK]

FIG. 31—RECEIVER END OPEN

Spacing 96 in. — f = 120 ~ — C = 3.03 mf. — L = 0.412 h. — E_g = 500 v. — E_r = 750 v. — I = 1.49 amp.



[MAGNUSSON AND BURBANK]

FIG. 34—RECEIVER END OPEN

Spacing = 96 in. — f = 25 ~ — L = 0.412 h. — C = 3.03 mf. — E_g = 2.50 v — E_r = 260 v. — I = 0.20 amp.

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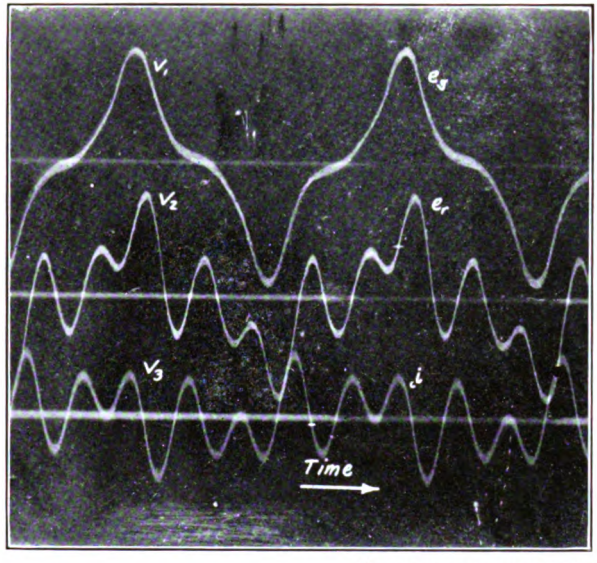
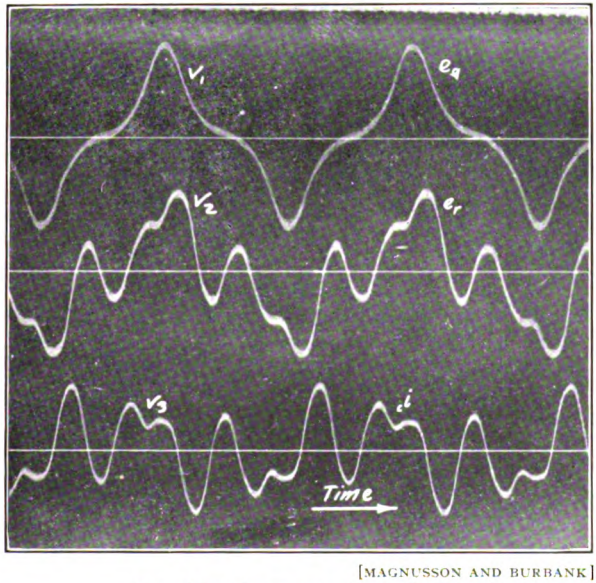


[MAGNUSSON AND BURBANK]

FIG. 35—RECEIVER END OPEN

Spacing 96 in. – f = 43.5 ~ – C = 3.03 mt. – L = 0.412 h. – E_g = 250 v. – E_r = 420 v. – I = 1.00 amp.



[MAGNUSSON AND BURBANK]

FIG. 36—RECEIVER END OPEN

Spacing 96 in. – f = 50 ~ – C = 3.03 mf. – L = 0.412 h. – E_e = 250 v. – E_r = 325 v. – I = 0.55 amp.

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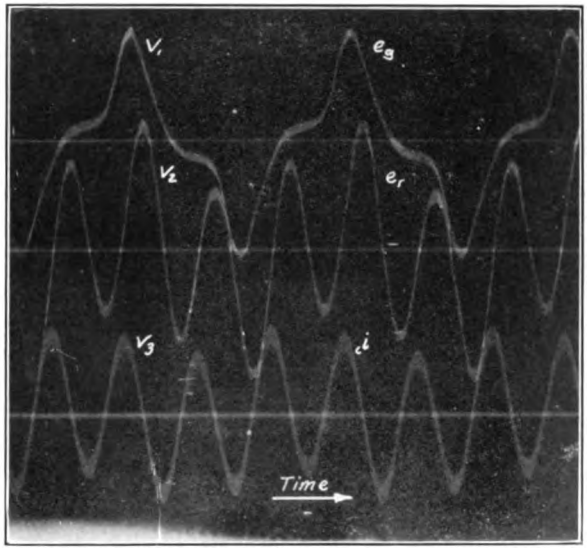

[MAGNUSSON AND BURBANK]

FIG. 37—REVEICER END OPEN

Spacing 96 in. — f = 72.5 ~ — L = 0.412 h. — C = 3.03 mf. — E_g = 250 v. — E_r = 860 v. — I = 2.5 amp.

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in Fig. 22, or at 72 cycles. The distortion is smaller at 100 cycles, Fig. 23, and practically disappears at 120 cycles, Fig. 24. The line constants give a resonance frequency of 222.2 cycles and hence for the third harmonic in resonance the fundamental frequency would be $\frac{222.2}{3} = 74$ cycles.

Similar oscillograms for a spacing of 96 in. (2.4 m.) and for frequencies of 60, 74 and 120 cycles are shown in Figs. 29, 30 and 31. The third harmonic is at a maximum for 74 cycles.

The dampening influence of the load on the receiver end is shown by comparing the voltage and current waves in Figs. 25, 26 and 27 with the wave shapes for the corresponding frequencies in Figs. 20, 23 and 24.

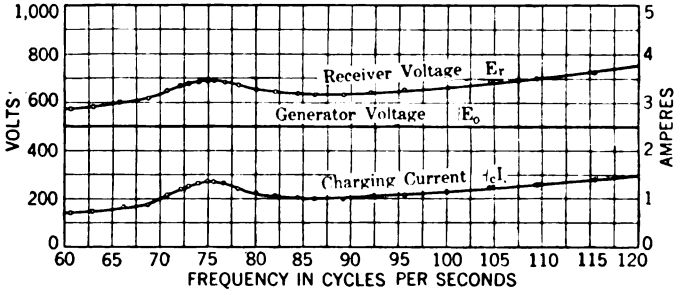

FIG. 28—RESONANCE CURVES WITH MACHINE GIVING NEARLY SINE WAVE AS SOURCE (ABOUT 1 PER CENT THIRD HARMONIC)

A much greater distortion is produced when using alternator *B*. The influence of the frequency for resonance conditions of both the third and fifth harmonics are shown in Figs, 34, 35, 36 and 37.

For 25 cycles, Fig. 34, the receiver voltage is practically of the same shape as the impressed voltage wave at the generator end. For 43.5 cycles the fifth harmonic produces resonance and causes a marked distortion of the receiver voltage. At 72.5 cycles, Fig. 37, the third harmonic is near resonance and the receiver voltage consists chiefly of the third harmonic. At 50 cycles, Fig. 36, the distortion of the receiver voltage is less than for either 43.5 or 72. 5 cycles.

Not only the wave shape but also the magnitude of the rereiver voltage is affected by the resonance of the harmonics in the impressed voltage wave. In Fig. 28 is shown the receiver

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voltage and charging current plotted as ordinates with the frequency of the impressed voltage from alternator A as abscissas. The voltage at the generator end of the line was held constant at 500 volts. The hump in the curve between 70 and 80 cycles is due to resonance produced by the third harmonic.

In Fig. 33, similar voltage and charging current curves are drawn for alternator B. The humps in the curves are produced by resonance in the line by the fifth and third harmonic.

The maximum point for the fifth harmonic comes at 43.5 cycles and for the third harmonic at 72.5 cycles. The great increase of the receiver voltage for resonance in the third harmonic should be noted; while at 85 cycles the measured receiver voltage drops

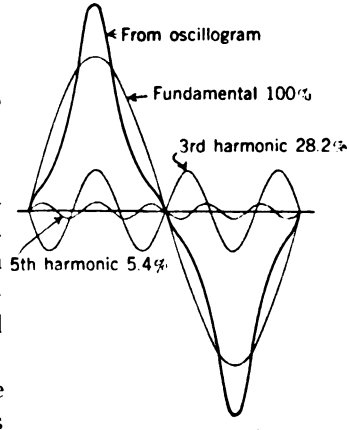

FIG. 32—ANALYZED WAVE OF PEAKED WAVE ALTERNATOR

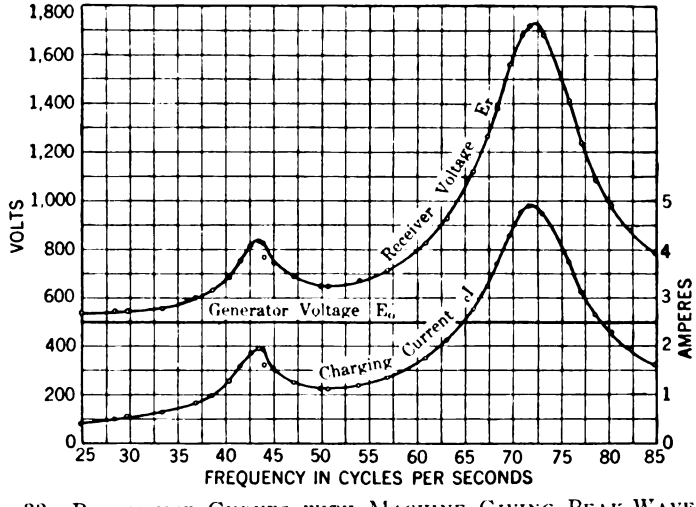

FIG. 33—RESONANCE CURVES WITH MACHINE GIVING PEAK WAVE, AS SOURCE—(5.4 PER CENT FIFTH AND 28.2 PER CENT THIRD HARMONIC)

to a comparatively low value, although considerably in excess of what would be produced by a simple sine wave.

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STEEL CONDUCTORS FOR TRANSMISSION LINES

BY H. B. DWIGHT

ABSTRACT OF PAPER

The electrical tests of some steel conductors of moderately large size have been published, and they indicate that there is an opening for the profitable use of steel cables on the branch lines of power systems of all voltages, in the same way that small steel conductors have already been used on branch lines at low voltages. Mechanical weakness or corona loss prohibits the use of small copper or aluminum conductors in many cases, and so steel becomes preferable.

Steel cables will not generally be economical on main transmission lines, except for long spans, and for high altitudes where corona is excessive. They may be advisable as bare conductors for direct-current railway feeders. They deteriorate more rapidly than copper conductors.

Steel cables for alternating current should be finely stranded and the different groups of wires should be spiraled in opposite directions. Fortunately, medium-priced grades of steel give better results with alternating current than some more expensive grades. The characteristic increase of resistance and reactance with increase of current or frequency may be valuable for limiting lightning and switching surges and short circuit currents.

As there are large differences in electrical characteristics between different grades of steel, it is desirable that tests of medium priced steel cables manufactured in America be made and published, so that the data can be used in the designing of transmission lines.

THE RESULTS of a number of tests of the electrical properties of steel wires and cables when used as conductors of alternating current, have been published. Although these tests are incomplete, especially as regards the use of steel conductors in America, they show some attractive possibilities, from both commercial and engineering points of view, for the use of steel instead of copper in certain classes of work.

Attention is here called to the peculiar properties, the advantages and disadvantages, of steel conductors, in order to point out the advisability of making complete tests of American grades of steel, so that electric power companies may make use of this material for the cases where it proves economical and

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advisable for transmission-line work. Already, small sizes of steel conductors have been used with success in America, and this practise may be extended by a knowledge of the characteristics of large steel cables.

As is well known, the resistance of an iron or steel conductor is considerably greater for alternating current than for direct current. This is partly due to the skin effect, that is, the crowding of the alternating current to the outside parts of the conductor by the alternating magnetic flux in the conductor, and partly to hysteresis, or iron loss, caused by the alternating magnetic flux in the steel. In the case of copper or aluminum transmission-line conductors of usual size, the skin effect increases the effective resistance only one or two per cent and so is practically negligible. But in the case of iron or steel conductors, the flux has a magnetic path, and so attains a value from 20 to several hundred times as great as in a non-magnetic conductor. The result is that the skin effect is very pronounced and the effective resistance is increased by a large amount, in some cases by 100 or 200 per cent or more. However, the conclusion should not be assumed that steel cables are unsuitable for alternating currents. The tests so far published go to show that it is as necessary for an iron a-c. conductor to have fine strands as for an iron core to have thin laminations. The tests also indicate that if the strands are moderately fine and are properly put together, the increase of resistance at 25 or 60 cycles may be kept down to a reasonably small percentage. This is shown in Figs. 1 to 6.

The curves shown with this paper have been derived from test curves published in the *Elektrotechnische Zeitschrift* of January 28, 1915. They refer for the most part to a grade of steel or iron, called H-oo, which is a medium grade recommended in the above article for alternating-current work. That its cost is reasonably low is indicated by the fact that two other grades of steel were tested, each stated to be purer and more expensive, and also to have greater skin effect, than the grade H-oo. Although the purer material has higher conductivity for direct current, it has also greater permeability to magnetism, which is a disadvantage. Thus the cheaper grade was found to be more suitable for a-c. work. The same conclusion was also stated in a recent bulletin, No. 252 of the Bureau of Standards, Washington, D. C., by J. M. Miller, who found that of the wires tested, the grade with the highest resistance to direct current

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had the lowest resistance to alternating current, and was also the least expensive. The tests on American steel wire described in the above bulletin show somewhat less skin effect than that of grade H-oo steel wires.

The tests on grade H-oo steel were originally expressed in centimeter units and were made at 50 cycles. The curves have been rearranged for English units and for 60 and 25 cycles, and put on a base of amperes per cable, so as to apply to American transmission-line conditions. The Bureau of Standards' tests described in Bulletin No. 252 show that at commercial frequencies the increase of resistance is approximately proportional to

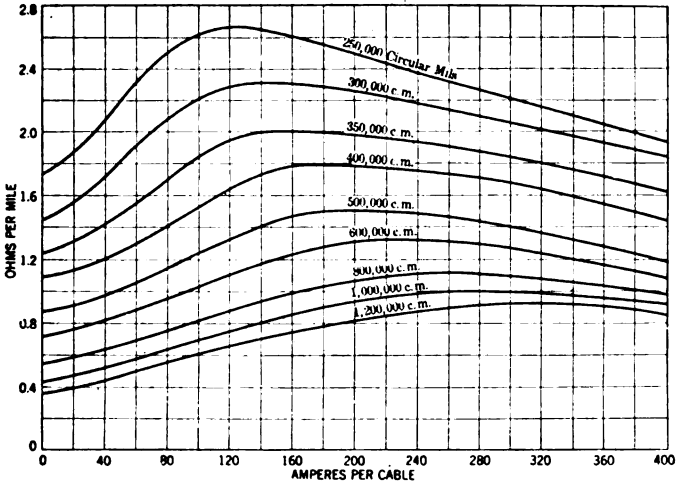

FIG. 1—RESISTANCE CURVES—60 CYCLES—49-WIRE CABLES—GRADE H-OO STEEL

the frequency, and this property was made use of in making the above transformations.

The curves of internal reactance of steel cables published in the article referred to above, are shown in Fig. 7. These curves do not refer to grade H-oo steel, but to a grade of higher permeability. This grade, as shown by resistance curves in the original article, has more increase of resistance than grade H-oo, for the same size and stranding of cable. Presumably, therefore, grade H-oo would have somewhat lower values of reactance than those of Fig. 7. The tests show that the resistance curve and the reactance curve of a given cable reach their maxima at about the same value of current. It is of inter-

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est to note that increasing the number of wires in a cable decreases the reactance, while increasing the size of the wires increases the reactance, according to the examples in Fig. 7.

The d-c. resistance of each cable is given in Fig. 7, and the

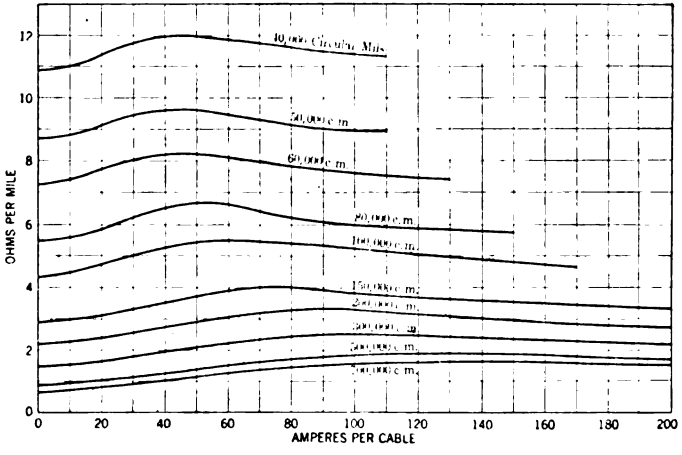

FIG. 2—RESISTANCE CURVES—60 CYCLES—19-WIRE CABLES—GRADE H-00 STEEL

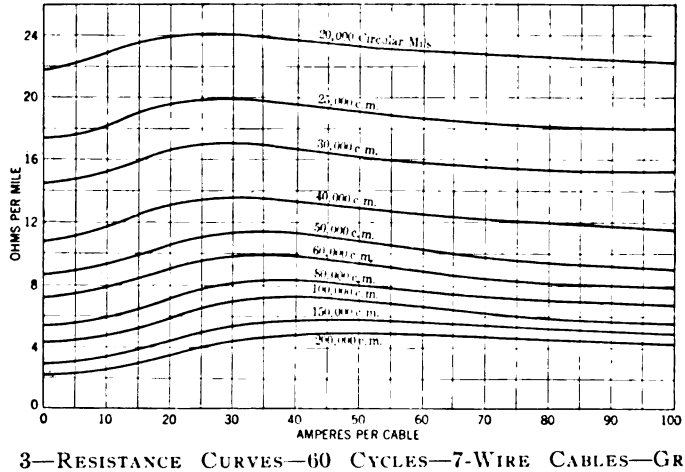

FIG. 3—RESISTANCE CURVES—60 CYCLES—7-WIRE CABLES—GRADE H-00 STEEL

maximum a-c. resistance will be about twice as great, according to Figs. 1 to 6. From the results shown in Fig. 7, the internal reactance at 60 cycles and at any current may be taken as being about 75 per cent of the a-c. resistance at the same current,

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in the absence of more complete data. The external reactance should be taken from regular transmission-line tables and added to the internal reactance to give the total reactance. The above is the method by which the examples at the end of this

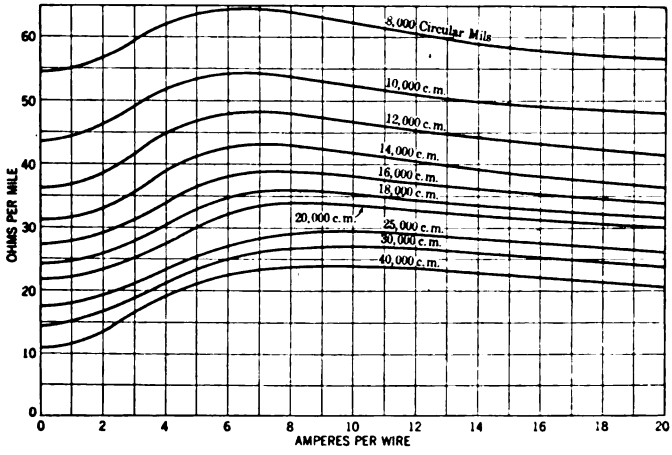

FIG. 4—RESISTANCE CURVES—GRADE H-00 STEEL WIRES— 60 CYCLES

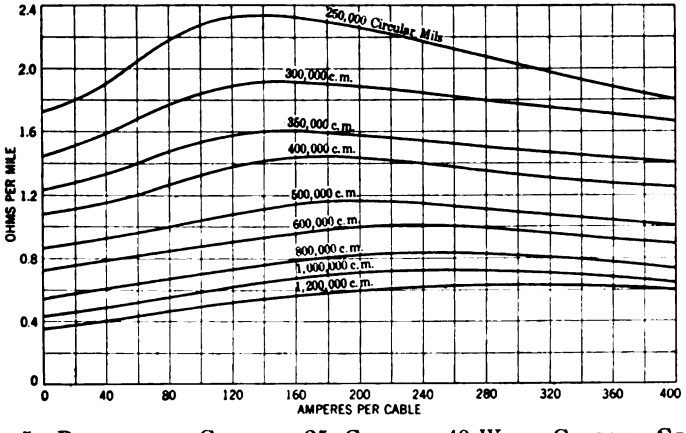

FIG. 5—RESISTANCE CURVES—25 CYCLES—49-WIRE CABLES—GRADE H-00 STEEL

paper have been worked. It is merely approximate, and the caution should be given that for practical designing, test curves of the resistance and reactance of the actual type of cable to be used should be employed.

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Another point brought out by the tests in the *Elektrotechnische Zeitschrift* is that a large part of the magnetization is caused by the spiraling of the wires in a cable, and if the spiraling of the different groups of wires is properly reversed, the increase in effective resistance can be reduced as much as one-half. Actual examples of this are shown in Fig. 8. Thus if the spiraling of one layer of wires is clockwise, the spiraling of the next layer should be counter-clockwise. Also, in a cable made up of several strands, the spiraling of the wires in each strand should be opposite to the spiraling of the strands in the cable. In Figs. 1 to 6, the cables are assumed to have the spiraling reversed as much as possible. Since spiraling produces so strong

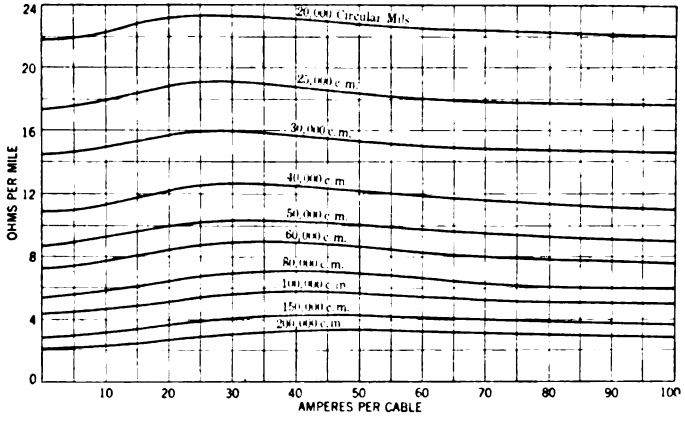

FIG. 6—RESISTANCE CURVES—25 CYCLES—7-WIRE CABLES—GRADE H-00 STEEL

an effect, the pitch of the spiral should be as long as possible without endangering the strength of the cable.

The curves accompanying this paper show that iron and steel conductors have the peculiar property that the effective resistance and reactance increase to a maximum as the current is increased, and then decrease. This is due evidently to the iron becoming saturated so that the flux and the iron loss do not increase as before in proportion to the current. In most cases, especially with the larger cables, the decrease is very slow and the resistance maintains approximately its maximum value for most large values of current. This property should prove useful in transmission-line work, for the conductor will have a low impedance to the normal load current, but will have about twice as much impedance to

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the current flowing in case of a short circuit. The impedance will also be large to high-frequency surges caused by switching or lightning. It may prove more economical in certain cases to protect a line against short circuits and surges by using steel conductors than by installing current-limiting reactors or by increasing the reactance of the transformers.

This property may also be of use in the case of feeders of direct-current interurban railways. If the feeder be a steel cable it will have low resistance to direct current, but high impedance to alternating currents. It will therefore tend to damp

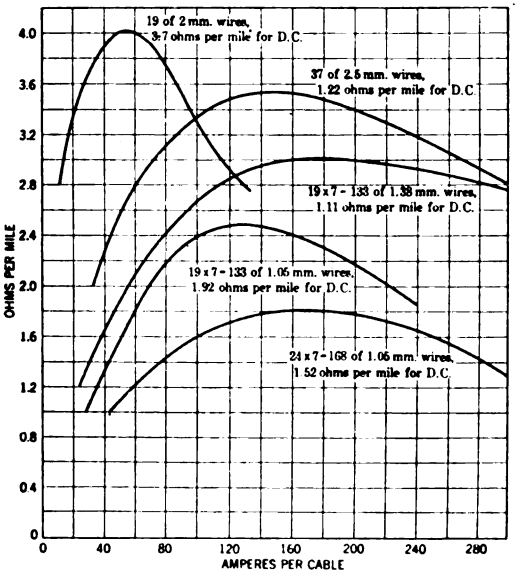

FIG. 7—INTERNAL REACTANCE CURVES—60 CYCLES—GRADE S.S.W. STEEL

out the suddenness of short circuits, and lightning surges, which cause synchronous converters and generators to flash over. That there is need of taking precautions against flash-overs in this way is shown by the fact that it has already become the practise to make the nearest connection between a feeder and the trolley wire several thousand feet from a synchronous converter or generator so that the latter will be protected by the resistance of a long stretch of feeder in case of surges or short circuits.*

*The Relation of Trolley Feeder Taps to Machine Flash-Overs, by Chas. H. Smith, *The Electric Journal*, January, 1915.

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If the feeder be made of steel, and especially if the stranding be coarse, the required protection will be still more complete. Steel conductors would probably be economical only where it is allowable to use bare cables, for the large size of steel cables compared with copper ones would greatly increase the cost of the insulating covering.

The higher conductivity of steel for direct current than for alternating current makes the use of bare steel cables for d-c. feeders more economical than for a-c. lines. A steel cable has about eight times as much resistance to direct current as a copper cable of the same size, and therefore seven times as much resis-

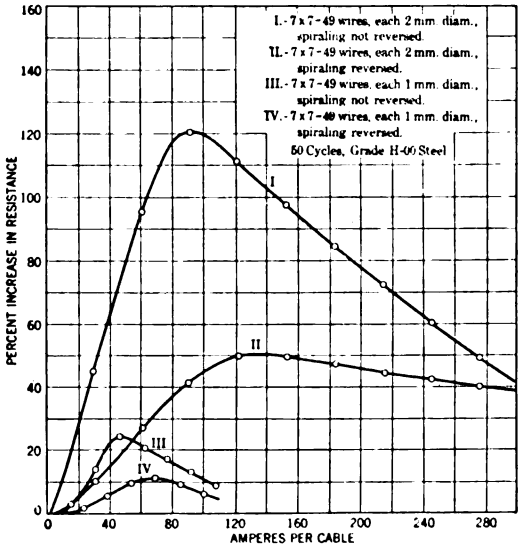

FIG. 8—EFFECT OF SPIRALING

tance as a copper cable of the same weight, since copper is more dense than steel. But galvanized steel cables usually cost less than 1/7 as much as copper cables per pound, and so should be more economical, other things being equal.

Steel cables have frequently been used on transmission lines for long spans up to 3000 feet or more. In some cases the steel cable has been the support for a copper conductor, but in many cases the steel cable itself has carried the electric current. Such applications are of such a short length compared with the entire transmission line that they have been chosen, not because of a comparison of the cost and conductivity of steel and copper, but

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because copper or aluminum would be too weak for such long spans, and a much stronger material, like steel, was absolutely necessary in order that the transmission line should be mechanically safe.

Another application of steel conductors which has already met with success is for small size conductors, as mentioned in the second paragraph. Here again it has not been the relative conductivity, but the greater tensile strength, which has induced the choice of steel rather than copper. It is not the practise to use a smaller copper wire than No. 6 (0.162 in. or 4 mm. diameter) for overhead lines, because any smaller copper wire would be mechanically too weak. But it is often profitable to supply a small load at a distance of several miles, which would require only a fraction of the conductivity of a No. 6 copper wire, and in such cases a No. 8 or larger steel conductor has been found to have sufficient conductivity and mechanical strength, and to cost much less than No. 6 copper.

According to a description recently published,* a large 60-cycle power system in the State of Washington makes use of a considerable quantity of No. 8 iron wire for short tap-offs and lightly loaded branch lines on 6600-volt circuits, without serious trouble resulting from voltage drop. This iron wire is of course far cheaper than No. 6 copper. One line built by the above company is an example showing that it may be profitable to supply a surprisingly small load at a distance of several miles. This line is 10 miles long and was originally built with No. 8 copper clad steel to supply a 50 h.p motor load at 6600 volts. The line afterward carried 110 h.p. for some time and was later changed to No. 6 copper in order to have a capacity for a still greater load.

An example from Minnesota shows the use of a somewhat larger steel conductor. This line operates at 40,000 volts, 60 cycles, and is 20 miles long. No. 4 galvanized steel cable, made of 3 wires, is used. The load is about 300 kv-a.

The above examples show that a power company can build up new loads by sending out to considerable distances numerous inexpensive lines, using small steel conductors. The cheapness of the lines and of the outdoor transformers makes a very small load profitable, and the chances of obtaining larger loads are increased by building lines into new territory. Most of the small steel

*_The Electrical World_, p. 469, Aug. 28, 1915. See also similar examples described in the _Electrical World_, p. 820, April 8, 1916.

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conductor lines appear to use solid wire of the kind which has been developed and sold for telegraph and telephone work, but a stranded cable would seem, according to the tests referred to in this paper, to be more suitable for a-c. transmission of power.

A line with small conductors, where steel is cheaper to employ than the minimum size of copper, is described in Example I. Here, a seven-mile steel line can be designed for 75 kv-a., but the smallest copper line that can be designed would be rated at 750 kv-a. Thus, while the poles and insulators will be the same in both cases, the steel conductors will cost only $220 against a cost of $2600 for copper. It is this large difference in cost which has been the main reason for using steel conductors on the branch lines of the power systems previously mentioned. This difference in cost of course is greatest when the price of copper is highest.

Besides being cheaper than the copper cable for small branch lines, the steel cable has the advantage of being mechanically stronger and less liable to be burned through by arcs. The steel line has therefore greater reliability at times of wind and sleet storms and at times of electrical breakdown or trouble. Steel cables are subject to the disadvantage that their useful life is shorter than that of copper cables, especially near the sea-coast, where galvanized steel is more quickly oxidized.

Example I shows also the advantage of using fine stranding. The seven-wire steel cable gives 9.6 per cent drop, while a solid steel wire of the same cross section has 12.5 per cent drop at the given load, according to the tests of grade H-oo steel.

Examples II and III show comparisons at 60 and 25 cycles between steel and copper conductors in regular transmission line work where the conditions are equal for competition between the two materials. The price of copper cable per pound may be assumed as being 10 times that of galvanized steel cable. This ratio is a usual one, being approximately true for times of low prices of metals as well as times of high prices. The lack of data on the reactance of a steel transmission line makes comparisons somewhat uncertain, but from the available data it seems probable that, considering the line complete with towers and insulators, it will cost for 60 cycles quite as much to use steel conductors as copper, for heavy transmission-line work, where the extra weight of steel cables is troublesome. For 25 cycles there may be a saving by using steel. However, there are many cases where the extra strength and size of steel cables are advantageous, and so at present the chief attention should

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be given to the classes of work where steel can show other advantages than merely low cost on a basis of carrying capacity for alternating current power.

A transmission voltage of 100,000 or more is now fairly common. It is also a matter of observation that the cost of high-tension substations of the above voltage is decreasing, especially where outdoor substations are used. It is not possible to use a small copper or aluminum conductor on a 100,000-volt line on account of corona loss, as is indicated by the corona limits of voltage given in examples II and III.* Therefore the phenomenon of corona puts a limitation on the smallest allowable conductor of a 100,000-volt branch line, in exactly the same way that mechanical strength fixes the minimum size of wire for a low voltage line, as previously described. Therefore, steel conductors have an opening for use on branch lines supplying a few thousand kv-a. on net works of 100,000 volts and higher. This is especially true in mountainous districts, where corona limits of voltage are lower, and where the other advantages of steel lines, namely mechanical strength and ability to resist burning by high-tension arcs, are especially valuable. In rugged country, also, the long spans permissible with steel cables may often save detours, and shorten the distance of transmission. There is also the probability, previously mentioned, that where steel conductors are employed, lightning and switching surges will be damped out more than where copper conductors are used.

In conclusion, it has been shown that large steel cables, if properly manufactured, can be used for carrying alternating currents. It appears that the chief opportunity for the use of steel conductors is on branch lines, where the size of copper required merely for the electrical load would be too small to use. However, in all cases, steel conductors will be nearly as cheap as copper ones, if not more so, and the use of steel will always increase the reliability of the transmission system.

EXAMPLE I

Length of line	7 miles
Voltage at receiver	11,000 volts
Frequency	60 cycles
Power factor of load	85 per cent
Phases	3

*These limits have been calculated according to the tables in "Dielectric Phenomena," by F. W. Peek, Jr., page 210, McGraw-Hill Book Co., New York, 1915.

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A.	Conductor	7-wire steel cable
	Size	25,000 cir. mils.
	Diameter of cable	0.18 inches
	Diameter of wires	0.06 inches
	Resistance per mile at full load	17.6 ohms
	Full load	75 kv-a.
	Voltage drop at full load	9.6 per cent
	Weight of conductors	7300 pounds
	Cost of steel cables at 3 cents per lb	$220
B.	Conductor	Single steel wire
	Size	25,000 cir. mil.
	Diameter	0.158 inches
	Resistance per mile at full load	23 ohms
	Full load	75 kv-a.
	Voltage drop at full load	12.5 per cent
	Weight of conductors	7300 pounds
	Cost of steel wires at 3 cents per lb	$220
C.	Conductor	Single copper wire
	Size	No. 6, 26,250 cir. mils.
	Diameter	0.162 inches
	Resistance per mile	2.14 ohms
	Full load	750 kv-a.
	Voltage drop at full load	9.5 per cent
	Weight of conductors	8800 pounds
	Cost of copper wires at 30 cents per lb	$2600

EXAMPLE II

	Length of line	75 miles
	Voltage at receiver	60,000 volts
	Frequency	60 cycles
	Phases	3
	Power factor of load	85 per cent
A.	Number of circuits	2
	Conductor	49-wire steel cable
	Size	400,000 cir. mil.
	Diameter of cable	0.81 inches
	Diameter of wires	0.09 inches
	Full load per circuit	2500 kv-a.
	Resistance per mile at full load	1.16 ohms
	Voltage drop at full load	9.6 per cent
	Weight of conductors for two circuits	2,510,000 pounds
	Corona limit for operating voltage at 1000 ft. above sea level	164,000 volts
	Sustained short circuit kv-a. at full generator voltage, transformers with 5 per cent reactance being included at each end	4.4 times full kv-a.
B.	Number of circuits	1
	Conductor	49-wire steel cable
	Size	1,000,000 cir. mil.

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	Diameter of cable	1.28 inches
	Diameter of wires	0.143 inches
	Full load	5,000 kv-a.
	Resistance per mile at full load	0.54 ohms
	Voltage drop at full load	10.9 per cent
	Weight of conductors	3,140,000 pounds
	Corona limit for operating voltages, at 1000 ft. above sea level	230,000 volts
	Sustained short circuit kv-a. at full generator voltage, transformers with 5 per cent reactance being included at each end	3.8 times full kv-a.
C.	Number of circuits	1
	Conductor	7-wire copper cable
	Size	No 1, 83,700 cir. mil.
	Diameter of cable	0.328 inches
	Resistance per mile	0.678 ohms
	Full load	5,000 kv-a.
	Voltage drop at full load	10.7 per cent
	Weight of conductors	300,000 pounds
	Corona limit for operating voltages, at 1000 ft. above sea level	85,000 volts
	Sustained short circuit kv-a. at full generator voltage, transformers with 5 per cent reactance being included at each end	4.8 times full kv-a.

EXAMPLE III

	Length of line	100 miles
	Voltage at receiver	60,000 volts
	Frequency	25 cycles
	Phases	3
	Power factor of load	85 per cent
A.	Conductor	49-wire steel cable
	Size	700,000 cir. mil.
	Diameter of cable	1.08 inches
	Diameter of wires	0.12 inches
	Resistance per mile at full load	0.68 ohms
	Full load	4, 000 kv-a.
	Voltage drop at full load	10.2 per cent
	Weight of conductors	2,930,000 pounds
	Corona limit for operating voltage at 1000 ft. above sea level	215,000 volts
	Sustained short circuit kv-a. at full generator voltage, transformers with 5 per cent reactance being included at each end	4.7 times full kv-a.
B.	Conductor	7-wire copper cable
	Size	No. 2, 66,400 cir. mil.
	Diameter of cable	0.292 inches

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Resistance per mile	0.855 ohms
Full load	4000 kv-a.
Voltage drop at full load	10.2 per cent
Weight of conductors	316,000 pounds
Corona limit for operating voltage at 1000 ft. above sea level	76,000 volts
Sustained short circuit kv-a. at full generator voltage, transformers with 5 per cent reactance being included at each end	5.6 times full k-va.

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(*Subject to final revision for the Transactions.*)

A DISTRIBUTION SYSTEM FOR DOMESTIC POWER SERVICE FROM COMMERCIAL AND ENGINEERING STANDPOINTS

BY CARL H. HOGE AND EDGAR R. PERRY

ABSTRACT OF PAPER

The adoption of electric heating and cooking has begun to reach such large proportions that the average distribution system is unable to take care of the increased load. As the domestic power load in all probability will increase until every house is electrically equipped, this paper has endeavored to lay out a distribution sysem to take care of this class of business and to estimate the revenue to be derived from it. Units of load, consumption and revenue were taken from tests conducted in different parts of the city and applied to a definite section of the city thought to be representative, as it contained every class of house, with schools, churches, etc. In view of the results obtained, it would seem that this business would be profitable at a still lower rate, and that it would be advisable for the central station man to make provision for this increased load when rebuilding any lines in the future.

DOMESTIC power is so rapidly attaining large proportions in the central station business that present distributing systems and practises are quite inadequate, and it is daily becoming more imperative to revise our methods to include this class of service. By domestic power we mean all the electricity that is used in the home, and have classed it thus:

Lighting, including ironing, wash machines, small motors and appliances of all sorts, excepting those used in preparing meals.

Cooking, including toasters, chafing dishes, etc.

Heating, all current consumed in keeping the house at a habitable temperature.

Hot water heating for such water as is consumed in the household.

The past few years have brought such rapid advances in the perfection of cooking and heating appliances that our distribution systems are beginning to groan under the load, having been designed to provide amply for illumination only. The downward trend of rates, such as Seattle has experienced, has

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MAP SHOWING HOUSES AND PROPOSED DISTRIBUTION SYSTEM.

TABLE I

CLASSIFICATION OF HOUSES

B = Large residence over 2 stories
C = Full two stories, medium size
D = Story and one-half, medium size
E = One story, medium size
F = One story, small size
St. = Store in a store building

Ch. = Church
Ap. = Apartment House, average about 20 apartments each
Apt. = One apartment in an apartment house
Sch. = School building of the Public School System
F.H. = Fire Apparatus Station

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done much to popularize the use of electric current for all purposes, and the central station man is becoming more concerned about the return from this class of business. Hence, we have prepared herewith a preliminary analysis of the ultimate conditions in five, or ten, or twenty years, when every house will be electrically equipped with light, cooking, heat and water heating, and have designed such a distribution system as would be required, keeping in mind the commercial aspects of the situation.

In order to arrive at definite ends we have made numerous assumptions of conditions, which are based on the most advanced knowledge of the present time, and from these have projected our hypothesis. A definite section of one of Seattle's leading residence districts was selected and from a thorough canvass each house was assigned to a class representative of its size and electrical consumption, as shown on the accompanying map, the key for which is given in Table I.

This district is known as Capitol Hill and is very representative as it includes houses of every type, with schools, stores, etc., and might be used as a " unit " in estimating similar conditions for a city. We have also assumed that all construction must comply with the State Law and City Ordinances governing overhead lines, and that the rights of other public service companies must be observed, and further that all apparatus, wire and materials shall be such as are now considered as standard. Our assumptions also provide that no further houses are to be built in this district and that property now vacant will be utilized for park purposes, so as to require no electrical energy.

During the past two years, we have conducted a series of tests on cooking and heating loads, the results of which have been indicative but not conclusive. Certain constants and factors have been determined, however, upon which we can base our computations. These factors are fully defined in Table II.

For the lighting we have taken a group maximum demand factor of 25 per cent as indicated by a check of conditions in this district; cooking has a demand factor of about 19 per cent; heating will average 50 per cent, while hot water heating as used here is a full 100 per cent. It is well to remember that these factors will vary materially with the kind of people who use the service and their daily habits, hence conditions obtaining in Seattle may differ materially from those in other cities. In the cooking tests, fifteen ranges in different parts of the city were

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selected, and by means of recording meters the characteristics of the load were determined. The heating tests included fifteen consumers who used all types of heating apparatus. From these sources then the data of Table III was selected, being the units of load, consumption and revenue assigned to each class of house. The rates applying to this business are quoted in Table VI. Having chosen suitable units, they were applied to the dis-

TABLE II
DEFINITIONS

Connected Load = Sum of the rated loads

$$\text{Group Maximum Demand Factor} = \frac{\text{Maximum of the resultant curve combining all the individual max's.}}{\text{Connected load}}$$

$$\text{Individual Maximum Demand Factor} = \frac{\text{Individual max. demand}}{\text{Connected load}}$$

$$\text{Group Daily Load Factor} = \frac{\text{Total kw-hr. consumed per day}}{\text{Group max. demand} \times 24}$$

Peak Demand Factor = Per cent of the group maximum demand that occurs during the system peak between 5:30 p.m. and 6:30 p.m.

$$\text{Individual Daily Load Factor} = \frac{\text{Kw-hr. consumed per day}}{\text{Max. demand} \times 24}$$

Peak Max Demand = Group max demand × peak demand factor

$$\text{Diversity Factor} = \frac{\text{Arithmetical sum of all the individual maximums}}{\text{Maximum of the resultant curve combining all the individual maximums.}}$$

The term "group" is here used to indicate all the appliances of one class, such as "water heaters." or "cooking," that occur in the district under discussion.

Lt. = Lighting, tc.
Ck. = Cooking, etc.
Ht. = Heating
WH. = Water Heating

trict outlined and the totals for this district computed, as in Table IV.

In order to properly design a distribution system to take care of heavy loads of this kind, it is necessary first to combine them into units; second, to determine the connected load in each unit from which the unit maximum demand can be figured using the group maximum demand factor; and third, to design a feeder system to take care of the load. For example, we find that in

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TABLE III.

UNIT OF LOAD, CONSUMPTION AND REVENUE

	No.	Connected load in kw.				Kw-hr. per mo.				Dollars per mo.			
		Lt.	Ck.	Ht.	W.H	Lt.	Ck.	Ht.	W.H.	Lt.	Ck.	Ht.	WH.
B	17	3	8	30	1.0	70	300	2130	720	3.00	6.00	16.0	3.50
C	321	2	6	20	0.8	30	224	1332	576	1.65	5.00	10.0	2.80
D	210	1.5	5	15	0.6	20	106	1000	432	1.10	3.00	7.5	2.10
E	57	1.0	5	5	0.5	13	94	667	360	.70	3.00	5.0	1.75
Apt.	145	1.0	5	5	0.5	25	166	667	360	1.40	4.00	5.0	1.75
Sch.	1	5.0	20	50	5.0	172	1000	13320	3600	5.00	20.00	100.0	17.50
Ch.	3	5.0	6	30	0.5	172	250	8000	360	5.00	5.00	60.0	1.75
St.	16	3.0	—	10	0.5	170	—	2670	360	5.10	—	20.0	1.75
F.H.	1	3.0	—	20	1.0	170	—	1332	720	5.10	—	10.0	3.50

TABLE IV.

TOTALS FOR DISTRICT

LOAD, CONSUMPTION AND REVENUE

	Connected load in kw.				Kw-hr. per month			
	Lt.	Ck.	Ht.	WH	Lt.	Ck.	Ht.	WH.
B	51	136	510	17.0	1190	5100	36200	12240
C	642	1926	6420	256.8	9630	71904	428000	184896
D	315	1050	3150	126.0	4200	22260	210000	90720
E	57	285	285	28.5	741	5358	38000	20520
Apt.	145	725	725	72.5	3625	24070	96700	52200
Sch.	5	20	50	5.0	172	1000	13320	3600
Ch.	15	18	90	1.5	516	750	24000	1080
St.	48	—	160	8.0	2720	—	42700	5760
F.H.	3	—	20	1.0	170	—	1332	720
Total	1281	4160	11410	516.3	22964	130442	890252	371736

	Dollars per month				Dollars per year			
	Lt.	Ck.	Ht.	WH.	Lt.	Ck.	Ht.	WH.
B	51.00	102	272	59.50	612	1224	3264	714
C	529.65	1605	3210	898.80	6356	19260	38520	10786
D	231.00	630	1575	441.00	2772	7560	18900	5292
E	39.90	171	285	99.75	479	2052	3420	1197
Apt.	203.00	580	725	253.75	2436	6960	8700	3045
Sch.	5.00	20	100	17.50	60	240	1200	210
Ch.	15.00	15	180	5.25	180	180	2160	63
St.	81.60	—	320	28.00	979	—	3840	336
F.H.	5.10	—	10	3.50	61	—	120	42
Total	1161.25	3123	6677	1807.05	13935	37476	80124	21685

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block No. 1 there are 14 class *C* houses and 12 class *D* houses having a connected load of 46 kw. in light, 460 kw. in heat, 144 kw. in cooking, and 18.4 kw. in hot water heating, a total of 668.4 kw. Using the group maximum demand factors as shown in Table V, we have 11.5 kw. in light, 27.8 kw. in cooking, 230 kw. in heat and 18.4 kw. in water heating, making a total of 287.7 kw. for the maximum demand of this unit. Proceeding similarly with blocks 5, 9 and 13, we find unit maximum demands of 310 kw., 273 kw. and 234 kw. respectively.

After covering the entire district in this manner, it seemed

TABLE V.

LOAD CHARACTERISTICS AND REVENUE

	Conn. load kw.	Group max. dem. factor	Group daily load factor	Max. dem. on peak	Peak dem. factor	Diversity factor	Group max. dem.	Aver. daily load kw.
Lt.	1281	25.00%	10.0%	320.	100.0	1.0	320	32
Ck.	4160	19.34%	22.5%	151.	18.81	2.5	805	181
Ht.	11410	50.00%	21.7%	5705.	100.00	1.5	5705	1238
WH.	516	100.00%	100. %	516.	100.00	1.0	516	516
Total	17367	38.6	29.4	6692.				1965

	Average kw-hr. per			Dollars per year	Av. rate per kw-hr.	Av. rate per kw-yr.
	Day	Month	Year			
Lt.	765	22964	275568	13935	5.06c	$43.50
Ck.	4348	130442	1563304	37476	2.40c	46.50
Ht.	29675	890252	10683024	80124	0.75c	14.00
WH.	12391	371736	4460832	21685	0.48c	42.00
Total	47179	1415394	16984728	153220	0.902	22.90

advisable to install a feeder from a centrally located sub-station for each 1000 kw. or thereabouts, which is the case in blocks 1, 5, 9 and 13. We find that in order to properly distribute 1000 kw. at 2300 volts, a three-phase, 4/0 feeder would be the most efficient, on account of initial cost, voltage regulation, carrying capacity of the wire and economy of space on the poles. We propose to maintain a constant voltage at the center of load on each feeder, and if necessary, to install transformers with variable taps to give the same voltage over the entire secondary. The load being essentially single-phase will necessitate instal-

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ling single-phase regulators on each circuit at the substation. As all standard apparatus for domestic use is built for 110 volts to 120 volts, we will string a 1/0 neutral over the entire system, which will give 120 volts between this wire and any outside leg of the three-phase, 207-volt secondary bus, and will provide a ground for the transformers. The secondary bus will be a 500,000-cir. mil cable, except in cases where the load is concentrated at the transformer. We propose to install transformers either in single-phase units or in one three-phase unit as near as possible to the center of load in each block or group of blocks, depending upon the load. On the accompanying map we have shown the distribution as outlined above, including transformers.

TABLE VI.

RATES FOR DOMESTIC SERVICE

Lighting and Cooking:

Electricity for these two purposes is sold through one meter, at the following rates:

First 45 kw-hr. per month @ 5½ cents per kw-hr.
All over 45 kw-hr. per month @ 2 cents per kw-hr.
Minimum charge 50 cents per month.

Heating:

Rate: 1 cent per kw-hr. unrestricted, or ¾ cents per kw-hr. if used off peak.
Peak hours are from 4:30 p.m. to 7:00 p.m. in winter.
All service has been figured at ¾ cents per kw-hr.

Water Heating:

Rate: Flat charge of $3.50 per kilowatt-month.
Heater to run continuously.

In order to determine a reasonable cost for this system, we have assumed prices of material and transformers that were current prior to the present war prices and have arrived at a total figure of $111,400.00. This includes all local distribution outside of the substation, services and meters.

In Table V the revenue from the business as outlined has been computed, making a gross of $153,220.00 per year. The kilowatt-hours total up to 16,984,728 per year, and the average rate for all classes of service is 0.9 cents. The average return is $22.90 per kilowatt-year.

In concluding, we believe that the development of domestic power will necessitate the complete reconstruction of existing lines. New substations will have to be built for each 10,000 kw. of load and located approximately at the center of the district

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served. The heavy load in this service will require three-phase distribution, which will also take care of small power loads. We believe that domestic power can be developed into a profitable part of the central station business, and sold at a price that will be attractive to the consumer. The present rate schedules, which necessitate two meters and a flat cut-in for this business, are not satisfactory and a new bases for charge must be developed that will utilize a simple, inexpensive meter and can readily be understood by the layman. With increasing volume of business, the rates can be lowered materially below those quoted herein, and still yield an adequate return. It is up to the central stations to make an intensive campaign for domestic power service, for this is the solution of the problem of profitably serving residence business.

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TEMPERATURE RISE OF INSULATED LEAD-COVERED CABLES

BY RICHARD C. POWELL

ABSTRACT OF PAPER

After a brief historical note the factors that determine the rating of a cable are considered.

The thermal conductivity of a cable is expressed in terms of the volume thermal conductivity of the insulation, the surface thermal conductivity of the lead sheath, and the dimensions of the cable. The values of the thermal conductivities as given by various observers including the author are compared. A diagram is shown for readily obtaining the thermal conductivities of one-conductor cables, and tables are given of the carrying capacity of one-conductor cables for various duct temperatures and thicknesses of insulation. Factors are added so that the carrying capacity of multiple-conductor cables may be taken from these tables.

Sometimes the lead sheath of a cable carries considerable stray current. A formula is given for calculating the increased temperature due to such current.

The carrying capacity of a cable is largely determined by the thermal properties of the duct line in which it is installed. This feature is discussed briefly.

The overload or intermittent rating is calculated from a formula involving the thermal capacity of the cable multiplied by a factor. Experimental values of this factor for several types of cables are given. A formula is given to take account of variable air temperature.

Various formulas given in the paper are developed in three appendixes.

I.—INTRODUCTION

THE limitation of the current-carrying capacity of electrical conductors due to heating effects has been a subject for investigation since 1849 when Joh. Müller[1] starting with Newton's Law of Cooling, arrived at the result that, for bare wires of the same material, the rise of temperature varies as the 1.5 power of the current. We now know this to be incorrect as the exponent is nearer 1.25. However, the subject was not

1. Glühen von Metalldrähten durch den galvanischen Strom. Bericht uber die neuesten Fortschritte der Physik. Band I.

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really seriously considered by engineers until taken up by Forbes[2] in 1882. Since then quite a number of investigators have published data relating to the heating of wires and cables, and a very good resume of the whole subject up to 1905 is given by Teichmüller in his "Die Erwarmung der Elektrischen Leitungen."

Since Eurpoean practise is to employ armored cables buried in the earth, we find very few European data of any real practical value to American engineers desiring information on lead covered cables for a draw in system.

It was not until 1905 when Fisher published the results of some quite extensive tests at Niagara that current ratings for lead-covered cables began to take definite shape. Based upon these tests, Fisher published in 1906 a table of current ratings, which has been quite extensively used by engineers.

This table is to be considered more as a good safe rule applicable under somewhat unfavorable conduit conditions rather than data which enable an engineer to rate a cable intelligently in accordance with the actual conduit conditions. It is to be noted that Atkinson in 1913 at the discussion of an Institute paper by Atkinson and Fisher, gave the results of some tests in a form more suited to the use of engineers. This paper and discussion will be referred to later.

Previous to the above mentioned table by Fisher, cables were usually rated according to some rule allowing a certain number of amperes per unit area, generally thousand circular units or square inch; and Fischer's work was a very great advance.

In order to expedite matters for a subject such as cable ratings, where there is an almost endless variety of conductor sizes, insulation thickness, types of make up, etc. and at the same time make it possible to compare properly the work of various investigators, the problem must be reduced to its simplest physical terms. That is, the complexity must be reduced by considering only the independent physical constants. Once these have been established, any engineer having the dimensions of a cable, and sufficient data upon the surrounding temperature may obtain a dependable rating cable.

In searching through the available literature, the writer has found only a few papers that conform to the above requirements and which may, therefore, be a basis for proper comparison. These are:

2. On the Thickness of Wires Required to Carry Different Electric Currents without Overheating. *Electrician* (London) 1882.

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Mie,—Über die Wärmeleitung in einem verseilten Kabel, *Elekt. Zeit.* 1905.

Melsom & Booth—The Heating of Cables with Current. *Jour. Inst. Elec. Engrs.* Vol. 47—1911.

Atkinson and Fisher—Current Rating of Electric Cables, TRANS. Am. Inst. Elec. Engrs. 1913.

Dushman—The Rating of Cables Carrying Current. TRANS. Am. Inst. Elec. Engrs. 1913.

The purpose of the present paper is to discuss more particularly the carrying capacity of paper-insulated cables, although it will be evident that much of what follows is applicable to cables insulated with other materials.

II—RATING OF CABLES

The rating of an insulated cable is determined by

A. —Continuous rating.

1. The maximum temperature at which the insulation may be operated without undue deterioration.
2. The thermal conductivity of the cable.
3. The thermal condition and properties of the surrounding medium, usually the air in a conduit system.

B. —Overload or intermittent rating, in addition to 1, 2, and 3 under A.

4. The thermal capacity of the cable and surrounding medium, that is, the ability of the cable to store a portion of the heat released in the conductor, and thereby, for short periods of time, to put less demand upon the cable as a dissipator of heat.

It is demonstrated in works on heat and is a fact so well known as not to require proof here that the thermal conductivity of an infinite hollow cylinder is watts per cm. of length per deg. cent. is

$$k_1 = \frac{2\pi\lambda}{ln\frac{d_1}{d}} \qquad (1)$$

in which λ = specific thermal conductivity of the material in watts per deg. cent. per cm.

ln = Naperian logarithm

d_1 = outer diameter of cylinder

d = inner diameter of cylinder

For a cable, d_1 and d are, of course, the inner diameter of the lead sheath and the diameter of the conductor respectively.

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In applying equation (1) to thermal measurements of cables, it is necessarily assumed that the conductor and the sheath are in very close contact with the insulation, and that there is no appreciable temperature drop from the conductor to insulation or from insulation to sheath. This assumption may not be correct; hence it is always always advisable to obtain values for λ from measurements on actual cables instead of from the insulation taped up on cylinders, etc. It may be said, however, that equation (1) when applied to cable measurements gives consistent values.

The surface thermal conductivity of the lead sheath to air is, in watts per cm. of length per deg. cent.

$$k_2 = \pi\, d_3\, h \qquad (2)$$

where h = specific surface thermal conductivity for lead to air in watts per deg. cent. per cm^2.

d_3 = outer diameter of the sheath in cm.

The thermal conductivity of the cable, that is, the watts per cm. per deg. cent. difference in temperature of the conductor and the air surrounding the lead sheath is

$$k = \frac{k_1\, k_2}{k_1 + k_2} \qquad (3)$$

This expression is at once recognized as that giving the electrical conductivity of two conductors in series and the analogous thermal conductors in series are the insulation and the lead sheath.

It is now readily seen that it is only necessary to agree upon values for λ and h in order to establish ratings for all one conductor cables. Various observers have obtained somewhat widely differing values for these.

VALUES FOR λ AND h.

Observer	λ for saturated paper	h for lead sheaths
Melson and Booth	0.00102 to 0.00134	0.00088 to 0.00155
Atkinson and Fisher	0.00100 to 0.00115	0.00083 to 0.0096
Powell	0.00081 to 0.00114	0.00090 to 0.0011
Dushman		0.00081 to 0.0011
[1]Symons & Walker	0.00142 to 0.0017	

1. The Heat Paths in Electrical Machinery, *Jour. Inst. Elec. Engrs.*, Vol. 48. These values were obtained by wrapping the paper on a copper cylinder which was then placed in an oil bath.

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It will be apparent, after examining into the conditions of the cables tested, that the above values are in reasonable agreement. Atkinson and Fisher state that they tested new cables with bright lead sheaths, and Dushman presumably made his tests upon new cables. The writers' values are from tests on old cables taken from service as well as on new cables, and it is to be especially noted that the variation in λ is greater than that given by any other observer, excepting Melson and Booth, and the writer is unable to state anything regarding the age of the cables tested by them.

The values 0.00114 for λ and 0.0009 for h were found for new cables with well saturated paper and bright sheaths, and are in very close agreement with the values by Atkinson and Fisher.

The value $h = 0.0011$ found by the writer for lead with discolored and roughed surface is the same as Dushman's value for lead painted black. It is, of course, well known that lead under these conditions is a better thermal dissipator.

The value 0.00081 for λ was measured upon a piece of 500,000-cir. mil. 5/32-in. lead cable which had been in service for a number of years. The paper was in excellent condition and of a very strong quality. It was so dry, however, that there was not a trace of free oil and it had the slightly translucent appearance of thick oiled paper. 'The writer has tested a number of pieces of old cables taken from service and the values for λ all ranged from 0.00081 to 0.00092, none showing so good values as for new, well saturated cables.

In the writer's opinion the degree of saturation and hence the age (since there is more or less continual drying action in service) has an important bearing upon the carrying capacity of paper insulated cables.

THERMAL CONDUCTIVITIES IN WATTS PER FT. PER DEG. CENT. OF NEW AND OLD PAPER-INSULATED CABLES

Size cir. mils	Thickness of insulation	Observer	
		Atkinson & Fisher A.I.E.E. 1913	Powell
500000	4/32	0.21	
500000	5/32		0.19
1,000000	4/32	0.275	0.26
1,000000 (new)	4/32		0.308
1,150000	4/32	0.31	0.318

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Although the thermal conductivity of the paper decreases with service, that of the lead increases, and the two effects just about balance, so that an old cable has nearly as good carrying capacity as a new one.

The values due to Atkinson and Fisher are for new cables and are those calculated from the table given in the discussion of their previously mentioned paper and increased by 12 per cent to agree with their test values. Except as noted, the writer's values are for old cables.

Values of λ *and* h *to be Used in Determining Carrying Capacity.* The above mentioned table recommended by Atkinson and Fisher is based upon $\lambda = 0.00100$ and $h = 0.000833$.

It is believed that the value of λ is too high for cables after several years service, and h is too low even for new cables after being exposed to the air for a few months. The writer, therefore, proposes ratings for paper cables based upon $\lambda = 0.00085$ and $h = 0.001$. First class cables, particularly, in a short time after installation, will usually show 15 per cent to 20 per cent greater carrying capacity than that calculated from these values, and most old cables of the same quality 10 per cent greater. However, allowance must be made for paper and saturation which may not be of the best, for inaccuracies of measurements on cables in a conduit system, and some uncertainty as regards heating due to sheath currents.

If t is the thickness of insulation in inches and $\lambda = 0.00085$, equation (1) becomes

$$k_1 = \frac{2\pi \times 0.00085}{ln\left(1 + \frac{2t}{d}\right)} \times 30.5$$

$$= \frac{0.1625}{ln\left(1 + \frac{2t}{d}\right)}$$

watts per ft. per deg. cent. **(4)**

Similarly, equation (2) becomes, if d_3 is in inches,

$$k_2 = \pi\, d_3 \times 0.001 \times 6.45 \times 12$$
$$= 0.244\, d_3 \text{ watts per ft. per deg. cent.} \quad \textbf{(5)}$$

These two equations suggest a comparatively simple diagram for obtaining k, the thermal conductivity of the cable. Such a

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diagram is Fig. 1, proof of which is given in Appendix I. To use the diagram proceed as follows:

Follow the ordinate through the given value of $\frac{2t}{d}$ to its intersection with the curve C, thence horizontally to the scale at the left. Through this point on the vertical scale and the value for d_3 on the lower horizontal scale pass the edge of a transparent triangle or straight edge, and the intersection of this with the line L is k read off on the vertical scale.

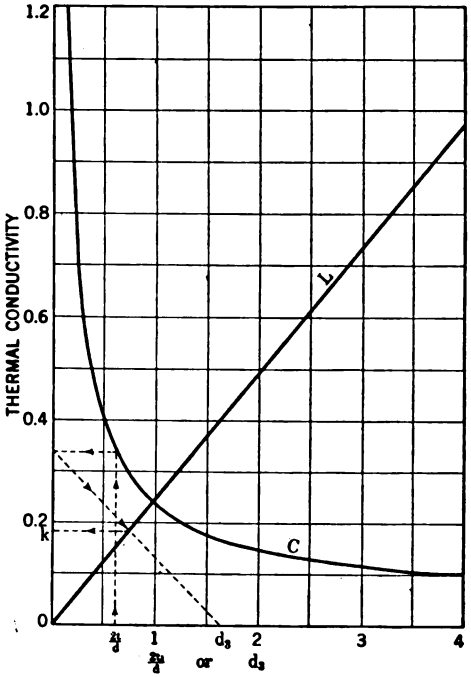

FIG. 1—DIAGRAM GIVING THERMAL CONDUCTIVITIES OF ONE-CONDUCTOR PAPER-INSULATED LEAD-COVERED CABLES.

With the help of this diagram, the three curves in Fig. 2 have been drawn. These curves give the thermal conductivities of one-conductor paper cables for various sizes of conductors and three thicknesses of insulation, viz. 4/32 in.; 8/32 in.; and 16/32 in. Values for any intermediate thickness of insulation may be readily interpolated.

As a maximum safe temperature for saturated paper 85 deg. cent., the value allowed in the Rules of the Institute may be ac-

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cepted with every assurance that it is conservative and does not represent the maximum temperature that this material will stand without deterioration. The Institute Rules call for a reduction from 85 deg. cent. of one degree for each thousand volts of operating voltage.

The maximum current carrying capacity, or the rating of a cable is given by

$$W_\theta = I^2 r_\theta = k\,(\theta - \theta_d) \qquad (6)$$

in which I = the current in amperes

W_θ = watts lost per ft. at temp. θ

r_θ = resistance, per ft. at temp. θ

θ = maximum allowable temperature for the conductor

θ_d = temperature of air in duct.

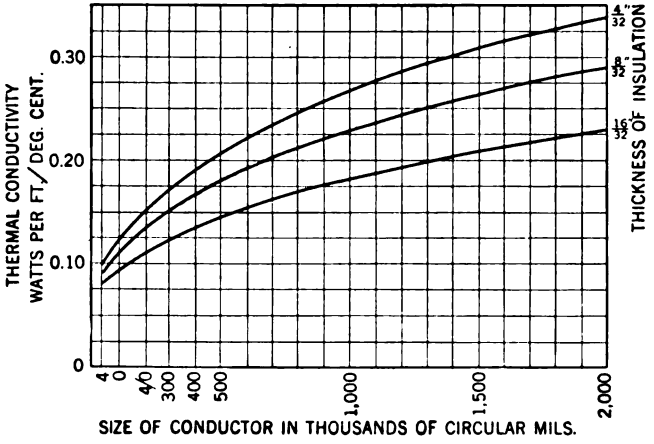

FIG. 2—THERMAL CONDUCTIVITIES OF ONE-CONDUCTOR PAPER-INSULATED LEAD-COVERED CABLES

It is sometimes assumed that the thermal conductivity of paper has a positive temperature coefficient comparable in value to the negative temperature coefficient of copper, so that the increase in loss due to the latter may be neglected. In order to check this point, the writer made the following test. The copper core was removed from a piece of 1,500,000 cir. mil 7/16 in. paper and $\frac{1}{8}$-in. lead cable about 75 cm. long. A heating coil was wound on a piece of insulated pipe and covered with asbestos taping to such a diameter as just to fit snugly into the space formerly occupied by the copper. This core was then wound with fine copper wire to be used as a thermometer coil,

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which was in rather good contact with the paper when the core was finally slipped into place. To guard against the escape of heat at the ends, they were filled for several inches with felt.

The values of λ for core temperatures of 75.5 deg. cent. and 118 deg. cent. differed by less than 2 per cent. The writer, therefore, concludes that the above assumption is incorrect. Moreover, it is to be particularly noted that the error in neglecting the temperature coefficient of copper is not on the safe side. In the following tables $\frac{1}{8}$-in lead has been assumed. Although the smaller cables invariably have thinner lead, the difference from $\frac{1}{8}$ in. is not sufficient to cause appreciable error.

III. Tables of Carrying Capacity, in Amperes, of One-Conductor Paper Insulated Lead Covered Cables.

TABLE I.

Insulation 4/32 in. Working Pressure 750 Volts. Maximum Temperature 85 Deg. Cent.

Size	Temperature of air in duct deg. cent.				
	30	40	50	60	70
4	133	120	106	90	70
3	154	139	122	104	80
2	181	164	144	122	95
1	200	182	160	136	105
0	240	220	192	163	126
2-0	277	250	220	187	145
3-0	320	290	256	217	168
4-0	376	340	300	254	197
250M	418	380	333	282	219
300	475	430	379	320	248
400	570	515	454	385	298
500	670	608	535	454	351
750	870	790	695	590	456
1000	1070	970	855	725	560
1250	1240	1120	990	840	650
1500	1410	1275	1125	950	735
2000	1700	1535	1355	1150	890

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TABLE II.

INSULATION 8/32 IN. WORKING PRESSURE 5000 VOLTS. MAXIMUM TEMPERATURE 80 DEG. CENT.

Size	Temperature of air in duct. Deg. cent.				
	30	40	50	60	70
4	125	112	97	79	56
3	145	129	112	91	64
2	166	149	129	105	74
1	181	162	140	115	81
0	214	192	166	135	96
2-0	251	225	195	159	112
3-0	290	259	225	183	130
4-0	339	303	262	214	151
250M	371	332	288	235	166
300	431	385	333	272	192
400	519	464	402	328	232
500	610	545	472	386	273
750	785	702	609	497	352
1000	955	855	740	605	427
1250	1100	980	850	695	490
1500	1255	1125	970	795	560
2000	1510	1350	1170	955	675

TABLE III.

INSULATION 16/32 IN. WORKING PRESSURE 15,000 VOLTS. MAXIMUM TEMPERATURE 70 DEG. CENT.

Size	Temperature of air in duct. Deg. cent.			
	30	40	50	60
4	107	93	76	53
3	122	106	86	61
2	139	120	98	70
1	152	132	108	76
0	181	157	128	90
2-0	208	181	147	104
3-0	239	207	169	120
4-0	284	246	201	142
250M	312	270	221	156
300	351	305	248	175
400	420	364	297	210
500	490	423	345	245
750	632	548	447	316
1000	766	664	542	383
1250	900	780	635	450
1500	1015	880	720	510
2000	1225	1060	855	610

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IV. Carrying Capacity of Multiple Conductor Cables

The preceding tables may be used for multiple conductor cables by applying the following factors to the carrying capacity of one-conductor cables having the same total thickness of insulation.

Number conductors	Type of cable	Multiply one conductor capacity by
2	Flat or Figure 8	87 per cent
2	Round	80 do
2	Concentric	75 do
3	Round	70 do
3	Oval Sector	77 do
3	Cloverleaf Sector	80 do
4	Round	67 do

Thus, the carrying capacity of a 4/32 × 4/32-in. round, three-conductor cable is 70 per cent of that for an 8/32-in. one-conductor cable.

The subject of multiple conductor cables is treated more fully in Appendix II.

V. Increase of Temperature Due to Sheath Currents

It happens, not infrequently, that cable sheaths carry considerable current. This current may be stray railway, or neutral or currents induced by alternating currents in neighboring one-conductor cables.

Let w = watts per ft. loss in conductor

w' = watts per ft. loss in sheath

k, k_1, and k_2 = thermal conductivities, for cable, conductor to sheath, and sheath to air, respectively.

θ = Conductor temperature above initial

θ' = sheath temperature above initial

Then $w = k_1 (\theta - \theta')$

$w + w' = k_2 \theta'$

Eliminating θ' we have

$$\theta = \frac{w}{k} + \frac{w'}{k_2}$$

or, the temperature of the conductor is increased by the amount $\frac{w'}{k_2}$, which is the temperature the sheath would have with the same current in the sheath but no current in the conductor.

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As an example; a 1,000,000-cir. mil 4/32-in., $\frac{1}{8}$ in. lead one-conductor cable which has a sheath resistance of 0.00017 ohms per ft. will operate at an increase in temperature of 5 deg., 17 deg. and 40 deg. with sheath currents of 100 amperes, 200 amperes and 300 amperes respectively. The effect of small or moderate sheath currents may be neglected, but large currents must be avoided.

VI. Cables in Duct Lines

The carrying capacity of a cable is largely determined by the thermal properties of the duct line in which it is installed, and hence, will vary greatly with type of construction and character of soil. In order to determine the proper carrying capacity of cables with any degree of reliability, it is necessary to make a temperature survey of the conduit system. Or, at least, sufficient data must be gotten covering the various types of construction and soil conditions to enable one to make a reasonably accurate estimate of temperatures.

It will be found that the thermal conductivity of a duct line is a constant, and is

$$k = \frac{w}{\theta - \theta_d} \text{ watts per ft. per deg. cent.} \qquad (13)$$

where w = total watts per ft. loss in duct lines.
θ = mean temperature of air in ducts
θ_d = temperature of air at surface of street

This equation will apply after the temperatures in the ducts have become steady, usually only after one or two weeks. It is to be noted that the temperature of the external air has an important bearing upon the subject and that, under otherwise similar conditions, a duct line will run much warmer in summer than in winter.

In practise, loads are seldom steady; hence, the temperature of the air in ducts follows, more or less closely, the load variations, although it will be found that the earth directly in contact with the conduit changes only with the seasonal variation of load.

The problem may conveniently be divided into two parts; viz., one having to do with heat transference from the air in the ducts to the earth directly in contact with the conduit, and the other with transference from the earth to the air at the surface.

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For the first, the thermal conductivity is

$$k_d = \frac{w_d}{\theta_d - \theta_s} \text{ watts per ft. per deg. cent.} \qquad (14)$$

In this, w_d = maximum watts per ft. loss at stationary maximum temperature θ_d for air in ducts.
θ_s = soil temperature.

For the second, we have

$$k_s = \frac{w_s}{\theta_s - \theta_d} \text{ watts per ft. per deg. cent.} \qquad (15)$$

where w_s = average watts per ft. loss for a given load cycle.

For most loads the cycle is probably a week.

All thermal measurements on duct lines should be made midway between manholes, as this is the warmest point. Soil under pavements which are a considerable distance from unpaved sections rarely has the variation in moisture content found in soil under unpaved streets. Hence, measurements in soil under pavements as above may be made at almost any time of the year, but in other soil should be taken at the dryest season.

The losses w_d and w_s may be calculated from the station load reports, and θ_d is taken with a recording thermometer. Measurements for θ_d should be taken in several ducts, particularly if there is a large number in the run.

After k_d and k_s have been obtained the effect of change in loading for the cables already installed, or effect of additional cables may be calculated.

Let w_d' be the maximum duct loss, and w_s' the mean loss over the cycle for the whole conduit, both in watts/ft. after the change. Then the new soil and duct temperatures are:

$$\theta_s' = \frac{w_s'}{k_s} + \theta_d$$

$$\theta_d' = \frac{w_d'}{k_d} + \theta_s' = \frac{w_d'}{k_d} + \frac{w_s'}{k_s} + \theta_d$$

It is hoped that the preceding discussion of duct line temperatures may assist in forming a clear conception of the physical principles involved. For only in this way may we expect to

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make a duct line in any degree, amenable to design as a dissipator of heat. The writer does not wish to leave the slightest impression, however, that judgment and experience are not of the highest importance in designing duct lines and may be replaced by some equations and a table of data. But unless backed up with quantitative information, "judgment and experience" are apt to be nothing but snap judgment and mental impressions.

If the large investments in duct lines and cables are to be operated with the greatest economy and reliability, it is very necessary that we increase materially our rather meager supply of information on the question of heating in conduit systems.

VII—Overload or Intermittent Rating

If a constant load, in amperes, is applied to a cable, the temperature rise of the conductor, at any time after application of the load, is given by the equation

$$\theta = \Theta\,(1 = \epsilon^{-\beta t}) = \frac{w}{k-\alpha w}\left(1-\epsilon^{-\frac{k-\alpha w}{c}t}\right) \qquad (11)$$

in which θ = temperature rise above initial temperature at time t,

Θ = final temperature rise,

ϵ = base of Naperian logarithms,

$\beta = \frac{k-\alpha w}{c}$ = constant,

t = time in hours.

w = watts loss per ft. at initial temperature.

α = temperature coefficient of copper referred to initial temperature.

c = constant depending upon thermal capacity of cable.

It is sometimes assumed that c is equal to the total thermal capacity of the cable, which is, of course, assuming that the rate of temperature rise is the same for all parts of the cable. This assumption is incorrect. It is at once apparent, for example, that the rate of temperature rise of the lead sheath is not so great as that of the conductor, particularly, for heavily insulated cables. The error is not appreciable for small cables, but for large well insulated cables the above assumption leads to results

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which are in error on the danger side, that is give too small a value for β and hence a lower temperature rise in a given time

We may put

$$c = c_1 + p\,(c_2 + c_3) \qquad (12)$$

where c_1 = thermal capacity of the conductor in watt-hr. per ft.

c_2 = thermal capacity of the insulation in watt-hr. per ft.

c_3 = thermal capacity of the lead sheath in watt-hr. per ft.

p = constant, depending upon the type of cable.

Some values for p as found by the writer follow:

EXPERIMENTAL VALUES FOR CONSTANT p.

No. conductors	Size conductor	Thickness of insulation	Thickness Lead	p
1	4/0	7/16 Paper	⅛	0.81
	500,000	5/32 "	⅛	0.70
	1,000,000	4/32 "	⅛	0.70
	1,500,000	4/32 "	⅛	0.77
3	4/0	13/64 × 13/64 Paper	⅛	0.595
	250 M Submarine (6/32 rubber + 2/32 Var Cl.) × 5/32 Var. Cl. 5/32 + 0.59		No. 4 Steel Armor Wires	

From data given by Dushman for a one-conductor 250,000, 4/32-in. rubber cable, p was found to be 0.80.

Hence, for practical purposes, it appears that we may put $p = 0.75$ for one-conductor and $p = 0.60$ for three-conductor cables.

The following quantities may be used in calculating the thermal capacity of a cable.

THERMAL CAPACITY IN WATT-HR. PER INCH CUBE

Copper, iron, steel	0.01525
Lead	0.0064
Rubber	.00625 (Dushman
Paper	.0047

For a further discussion of equations (11) and (12) see Appendix III.

In Fig. 3, is shown some test curves together with those plotted from equations of the form of (11).

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With the assistance of a curve, Fig. 4 giving $(1 - \epsilon^{-\beta t})$ for various values of βt, we may very readily obtain the temperature at any time t, provided the final temperature Θ, and the

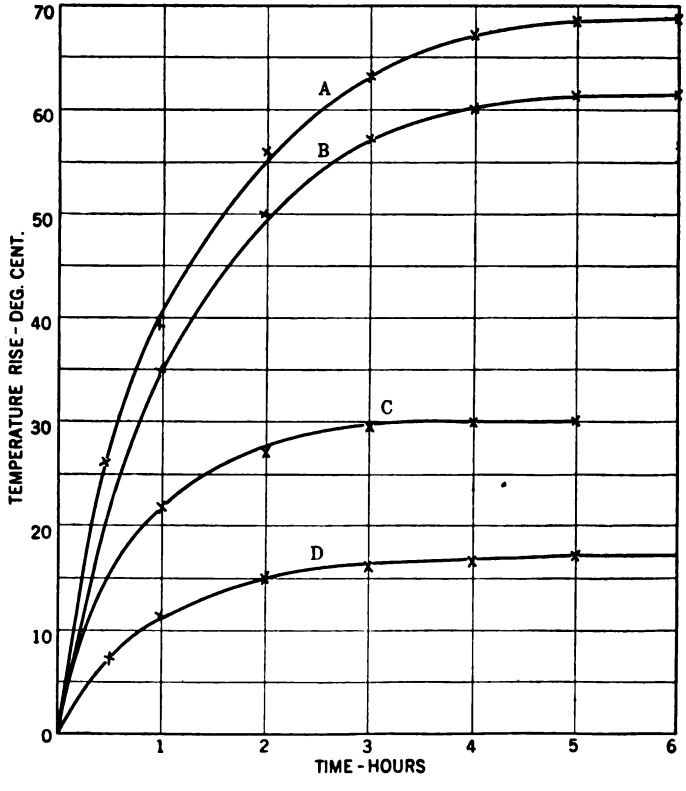

FIG. 3—RATE OF TEMPERATURE RISE OF CABLES

Curve	Type of cable	Load amps.	Equation
A	4/0-3 conductor round 13/64 × 13/64 paper ⅛"lead	300	$\theta = 69\,(1 - \epsilon^{-0.83\,t}$
B	1,500,000 c.m. 1 conductor 4/32 Paper ⅛ lead	1500	$\theta = 62\,(1 - \epsilon^{-0.86\,t}$
C	500,000 c.m. 1 conductor 5/32 Paper ⅛ lead	500	$\theta = 30\,(1 - \epsilon^{-1.4\,t}$
D	250,000 c.m. 3 conductor submarine (6/32 Rubber + 2/32 var. cl.) × 5/32 Var. Cl. 5/32 lead and 41 No. 4 Steel Armor Wires.	310	$\theta = 17\,(1 - \epsilon^{-1.05\,t}$

Points calculated from equations shown X.

time constant β are known. These, however, may easily be computed with the preceding equations and data.

For example, let it be required to find the time for a 1,000,000-cir. mil 4/32-in. paper cable to reach 85 deg. cent. starting at a

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temperature of 40 deg. cent. with a load of 1200 amperes. It is assumed that the temperature of the surrounding medium remains constant at 40 deg.

w, at 40 deg., = 17.0 watts per ft.
α (40 deg. reference) = 0.0036
k = 0.27
c = 0.21

$$\Theta = \frac{w}{k - \alpha w} = \frac{17.0}{0.21} = 81 \text{ deg. cent.}$$

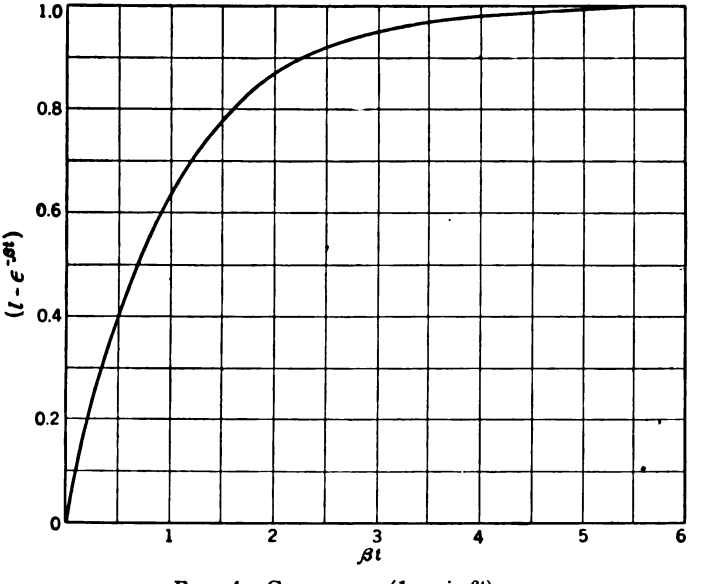

FIG 4—CURVE OF $(1 - \epsilon^{-\beta t})$

The rise is to be 45 deg., hence

$$\frac{45}{81} = (1 - \epsilon^{-\beta t}) = 0.555$$

From the curve (Fig. 4), we find $\beta t = 0.8$

But $\beta = \frac{k - \alpha w}{C} = \frac{0.21}{0.21} = 1.0$,

and therefore, t = 0.8 hour, or about 50 minutes.

In general, the duct temperature increases simultaneously with that of the cable, and usually at approximately the same

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rate. If this increase is small, that is, 5 or 10 deg., we may simply add this increase to the final temperature. For instance, in the above example, if the final duct temperature had been 50 deg. instead of 40 deg., we should have had $\Theta = 91$ deg. and the time about 40 minutes.

If the increase in duct temperature is large, the temperature coefficient of copper should not be neglected. A more correct value for the final rise of a cable is

$$\Theta = \Theta_1 + \frac{k}{k - \alpha w}\Theta_2$$

Here, Θ_1 is the final rise the cable would have at constant duct temperature, and Θ_2 is the final increase of duct air tempera-

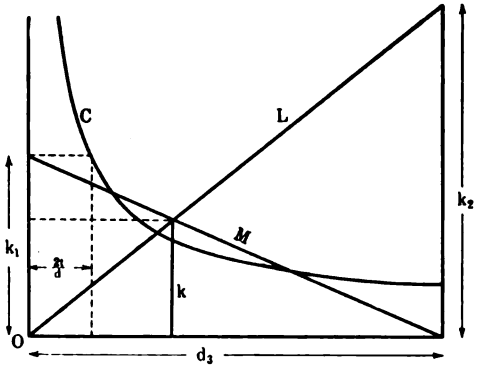

FIG. 5

ture. For the general equation involving variable air temperature see Appendix III.

Many of the cable tests, from which the data given above were taken, were made by the Laboratory Department of the Pacific Gas and Electric Company, San Francisco, and the writer desires to thank Mr. Knopp, the Superintendent and his staff for the very careful manner in which these were done.

APPENDIX I.

DIAGRAM FOR FINDING THERMAL CONDUCTIVITIES OF ONE CONDUCTOR CABLES

This construction is based upon a well known geometric construction which is sometimes used for finding graphically the circuit resistance of two resistances in parallel.

Two perpendicular distances k_1 and k_2 (Fig. 5) are erected at

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the ends of a given line and the top of each is joined to the foot of the other by a straight line (the lines L and M in the figure). The perpendicular dropped upon the base line from the intersection of these two lines (k in the figure) is connected to k_1 and k_2 by the relation

$$\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2}, \text{ or } k = \frac{k_1 k_2}{k_1 + k_2}$$

By plotting the equation $k_1 = \dfrac{0.1625}{ln\left(1 + \dfrac{2t}{d}\right)}$ the curve C is obtained giving k_1 for any value of $\dfrac{2t}{d}$.

The straight line (L in the figure), $k_2 = 0.244\, d_3$, is next drawn. After the point k_1 is found by means of the curve C, k is given, for any value of d_3 by the intersection of the line L and the line M through k_1 and the point P distant d_3 from 0. The thermal conductivity k is, of course, read off on the same scale as k_1.

It is more convenient to place a transparent straight edge through k_1 and d_3 than actually to draw the line.

APPENDIX II

Multiple Conductor Cables

The thermal conductivity, k_1 from conductors to sheath for multiple conductor cables having the conductors laid up in a single layer may be calculated from an equation given by Mie in his paper mentioned above. This equation covers the usual two-, three-, and four-conductor cables for power purposes, and is

$$k_1 = \frac{2\, n\, \pi\, \lambda}{ln\, [(1 - \alpha\beta) + \sqrt{(1 - \alpha^2)\,(1 - \beta^2)}} \text{ watts per ft. per deg. cent.} \quad (7)$$

in which n = number of conductors

$$\alpha = \left(\frac{R_1}{R_2}\right)^n$$

$$\beta = q\,\alpha\,, \quad q = \frac{R_1 - (n+1)\,r}{R_1 + (n-1)\,r}$$

r = radius of conductors

R_1 = radius of circle circumscribing the conductors

R_2 = inner radius of lead sheath

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R_1 and R_2 depend upon the size and number of conductors and thickness of insulation.

If t_1 and t_2 are the thicknesses of insulation for conductors and belt respectively, then

$$R_2 = R_1 + t_1 + t_2$$

and $R_1 = 2r + t_1$, for two-conductor round cables

$$R_1 = \frac{2(r + t_1)}{\sqrt{3}} + r = 2.16r + 1.15t_1 \text{ for three-conductors}$$

$$R_1 = \frac{2(r + t_1)}{\sqrt{2}} + r = 2.42r + 1.41t_1 \text{ for four conductors}$$

The quantity $(1 - \alpha\beta) + \sqrt{(1 - \alpha^2)(1 - \beta^2)} \equiv m$ is approximately a constant for a given type of cable, and the following values may be used,

1.90 for two conductors, and

1.96 for three and four conductors.

Equation (7) may, therefore, be somewhat simplified. We may put

$$R_1 = (a + b)\, r$$

whereupon, $\alpha - \beta = \alpha(1 - q) = \alpha \dfrac{2n}{a + b + n - 1} = \alpha C,$

and, finally, $$k_1 = \frac{2\pi\lambda}{l n \dfrac{R_2}{R_1 \sqrt[n]{\dfrac{C}{m}}}} \qquad (8)$$

That is, a multiple conductor cable has the same thermal conductivity as a one conductor cable of the same outside sheath diameter and a conductor diameter equal to

$$2 R_1 \sqrt[n]{\frac{C}{m}} = 2f R_1$$

In practise, it is scarcely worth while to make calculations for the various sizes of conductors and thicknesses of insulation as it will be discovered that the factors for applying to one conductor cable ratings do not differ by more than 5 per cent. To find the carrying capacity of a multiple conductor cable, apply the

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following percentages to the carrying capacity of a one conductor cable having the same total thickness of insulation.

No. Conductors	Multiply One-conductor Capacity by
2	80 per cent
3	70 " "
4	67 " "

Two-Conductor Flat and Three-Conductor Sector Cables

In addition to the above there are frequently used two conductors flat and figure 8, and multiple sector cables. Sector cables are of two types, oval and clover leaf. The oval is laid up with fillers and the clover leaf without. It is evident that sector cable has greater carrying capacity than round, and that the clover leaf is somewhat better in this respect than the oval. The writer has found by test that a 4/0, 13/64-in. × 13/64-in. paper, three-conductor, oval sector cable has 12 per cent better carrying capacity than a similar round cable.

It is believed that the following percentages may safely be applied to two-conductor flat and three-conductor sector cables.

Type of Cable	Multiple One-conductor Capacity by
2 Conductor, flat	87 per cent
3 " Oval sector	77 " "
3 " Clover leaf sector	80 " "

Two Conductor Concentric Cable

Concentric cable is sometimes used for direct current feeders where duct capacity is limited.

Let d = diameter of inner conductor,
d_1 = inner diameter of outer conductor
d_2 = outer diameter of outer conductor
d_3 = inner diameter of sheath
d_4 = outer diameter of sheath

$$a = \frac{\text{total area of both conductors}}{\text{area outer conductor}}$$

The slightly increased loss in the inner conductor due to operating at a little higher temperature than the outer may be neglected. Sometimes the area of the inner conductor is made larger in area than the outer.

The thermal conductivity is

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$$k = \frac{(a\ k_1) \cdot k_2'}{(a\ k_1) + k_2'} \text{ watts per ft. per deg. cent.} \qquad (10)$$

in which $k_2' = \dfrac{k_2\ k_3}{k_2 + k_3}$,

$$k_1 = \frac{2\ \pi\ \lambda}{l\,n\ \dfrac{d_1}{d}}$$

$$k_2 = \frac{2\ \pi\ \lambda}{l\,n\ \dfrac{d_3}{d_2}}$$

$$k_3 = 0.244\ d_4$$

The carrying capacity of a two-conductor concentric cable with conductors of equal area may be taken as 75 per cent of that for a one-conductor cable.

Increasing the size of the inner conductor is of very little advantage, for example, a concentric cable with 1,250,000 cir. mil inner conductor and 1,000,000 cir mil out has only about 9 per cent greater carrying capacity than a cable with both conductors 1,000,000 cir. mil.

APPENDIX III.

Rate of Temperature Change of a One-Conductor Lead-Covered Cable

In order to develop the theory of temperature rise of cables, one might follow along the usual lines of mathematical physics, but it will soon be evident that the mathematical difficulties are such that a rigorous development is not suitable for engineering purposes. The following discussion may be of interest.

It may be shown experimentally that the following equation, which is only approximately true but sufficiently so for engineering use, gives the rise of temperature of any part of a one-conductor cable from the time load is first applied:

$$\theta_r = \Theta_r\ (1 - \epsilon^{-\beta t}) \qquad (1)$$

in which θ_r = temperature at time t and at any point P between the conductor and the lead sheath distant r from the axis of the cable, including also the conductor and the sheath.

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Θ_r = final temperature ($\alpha t\ t = \infty$) at the point P.

ϵ = base of Naperian logarithms

β = constant for any given cable and loading.

With this assumption, the quantities Θ_r and β may be expressed in terms of known physical constants and the dimensions of the cable.

In the following, all temperatures are in degrees centigrade above the initial temperature assumed constant.

Let w = watts per cm. loss in cable at initial temperature.

α = temperature coefficient of copper referred to initial temperature.

θ = temperature of conductor at time t

θ_r = temperature of insulation at time t at point distant r from cable axis.

θ_b = temperature of lead sheath at time t

Θ = final temperature of conductor.

Θ_r = final temperature of insulation at point distant r from cable axis.

Θ_b = final temperature of lead sheath.

C_1 = thermal capacity of conductor in watt-hrs per cm.

C_2 = thermal capacity of insulation in watt-hr. per cm.

C_3 = thermal capacity of sheath in watt-hr/cm.

ρ = density of insulation, grams per cm.^{3}

c = specific heat of insulation watt-hr. per gram.

λ = volume thermal conductivity of insulation; watts per deg. per cm.

h = surface thermal conductivity of sheath to air, watts per deg. per cm.^{2}

a = radius of conductor

b = inner radius of sheath

d_3 = outer diameter of sheath

The following equation expresses mathematically the fact that the heat generated in the conductor is equal to that stored in

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the copper, insulation and lead plus that dissipated at the surface of the lead.

$$w\,(1+\alpha\,\theta) = C_1 \frac{d\,\theta}{dt} + \int_a^b 2\,\pi\,\rho\,c\,r\,\frac{d\,\theta_r}{dt}\cdot dr + C_3\,\frac{d\,\theta_b}{dt} + \pi\,h\,d_3\theta_b \tag{2}$$

Differentiate equation (**1**) and

$$\left.\begin{aligned} \frac{d\,\theta}{dt} &= \beta\,\Theta\,\epsilon^{-\beta t}, \\ \frac{d\,\theta_r}{dt} &= \beta\,\Theta_r\,\epsilon^{-\beta t}, \\ \text{or,}\qquad \frac{d\,\theta_r}{dt} &= \frac{\Theta_r}{\Theta}\cdot\frac{d\,\theta}{dt}. \end{aligned}\right\} \tag{3}$$

Substituting this value for $\frac{d\,\theta_r}{dt}$ in (**2**) and evaluating the integral, we find after substituting

$$k_1 = \frac{2\pi\lambda}{ln\,\frac{b}{a}},\quad k_2 = \pi\,d_3\,h,\text{ and } k = \frac{k_1\,k_2}{k_1+k_2}$$

that

$$w\,(1+\alpha\,\theta) = \left[\, C_1 + \rho\,c\left\{\pi\,(b^2-a^2)\left(1+\frac{k}{4\,\pi\,\lambda}\right) - \frac{\pi\,k\,b^2}{k_1}\right\} + C_3\,\frac{k_1}{k_1+k_2}\right]\frac{d\,\theta}{dt} + k\,\theta$$

Or, we may write this in the form:

$$w\,(1+\alpha\theta) = C\,\frac{d\,\theta}{dt} + k\,\theta \tag{4}$$

in which

$$C = C_1 + p_2C_2 + p_3C_3$$

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$$p_2 = \left(1 + \frac{k}{4\pi\lambda}\right) - \left(\frac{k\,b^2}{k_1\,(b^2 - a^2)}\right)$$

$$p_3 = \frac{k_1}{k_1 + k_2} = \frac{k}{k_2}$$

In practise, we may approximate further and put

$$C = C_1 + p(C_2 + C_3)$$

The integral of (**4**) is

$$\theta = \frac{w}{k - \alpha w}\left(1 - \epsilon^{-\frac{k - \alpha w}{c} t}\right) \qquad (5)$$

Variable Air Temperature

Since the change of air temperature in a duct line or other location where cables are usually installed is due to increased load on the cables, an equation of form (**1**) will express the temperature change for the air. Let this equation be

$$\theta_a = \Theta_a\,(1 - \epsilon^{-\beta_a t}) \qquad (6)$$

in which the temperatures as before are those above the initial temperature.

The equation of heat balance for the cable now becomes

$$w\,(1 + \alpha\theta) = C\frac{d\theta}{dt} + k\,(\theta - \theta_a) \qquad (7)$$

and the solution is

$$\theta = \Theta_1\,(1 - \epsilon^{-\beta t}) + -\frac{k\,\Theta_a}{C\,(\beta - \beta_a)}\,(1 - \epsilon^{-\beta_a t}) - \frac{k\,\beta_a\,\Theta_a}{C\,\beta\,(\beta - \beta_a)}\,(1 - \epsilon^{-\beta t}) \qquad (8)$$

In which

$$\Theta_1 = \frac{w}{k - \alpha w}$$

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For most practical purposes, one may put $\beta_a = \beta$ so that (8) becomes

$$\theta = \left(\Theta_1 + \frac{k}{k - \alpha w}\Theta_a\right)(1 - \epsilon^{-\beta t}) \qquad (9)$$

That is, the final temperature of the conductor is greater by the amount $\frac{k}{k - \alpha w}\Theta_a$ over what it would have been with constant air temperature.

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DISCUSSION ON "HIGH-VOLTAGE D-C. RAILWAY PRACTISE (RENSHAW), NEW YORK, APRIL 14, 1916 (SEE PROCEEDINGS FOR APRIL, 1916).

(Subject to final revision for the Transactions.)

Frank J. Sprague: Mr. Renshaw's interesting paper offers a gratifying opportunity for reflection to one who has been identified with the development of electric railway advancement since its commercial inception, and who may fairly claim to have played a not inconsequential part in that development. It offers a luminous example of what is known in law as a plea of "confession and avoidance," and illustrates, somewhat tardily, the old adage that it isn't always safe to prophesy.

I think no engineer of our profession has met with more bitter criticism, or stood for a time more alone than I did, because of my having more or less gently, although possibly sometimes strenuously, raised my voice in remonstrance at the subordination of the future of the electric railway on one hand to a fixed ambition, that of the supremacy of the single-phase railway, and on the other to commercial catholicism, instead of realizing that "evolution and not revolution" must be the order in electric railway development; and because of these reasons I had urged the vital necessity, whatever the promise or hope with regard to the new system, of also carrying the d-c. development to its logical conclusion.

Mr. Renshaw states that ten years ago the idea of approximately 600 volts as the maximum potential to be hoped for in d-c. railway operation was almost as firmly established as was the belief in the days of Columbus that the world was flat. Why the present change of heart? Who or what has been the cause?

The time seems opportune to add something to Mr. Renshaw's statement from a much needed bibliography of the art, and I think perhaps no one is in a position to more correctly state that although that fixity of belief was held by at least one great organization, and in a large measure by electrical railway engineers, I can, at the risk of comparison with the famous discoverer, claim that some engineers at least were not deluded with this conviction.

In the early days of stationary motor development I had built some special machines to operate normally at from 500 to 600 volts but which in the exigencies of service had been boosted to about 1000 volts; and in my experience on the 34th Street branch of the Manhattan Elevated in the latter half of 1886, where a number of the primary features of the modern electric railway were tried out, I operated at 600 volts from a third rail.

When, a year later, I took the contract for the pioneer trolley roads at Richmond and St. Joseph, I adopted a somewhat lower potential, 450 to 500 volts, which pressure and system were, however, even then regarded as the product of a disordered brain. This standard was gradually raised, however, to about

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600 volts, and remained there for practically twenty years, until the reincarnation, for the practical construction of inter-pole motors for stationary purposes, of the identical system of cross-winding initiated by me for stationary motors in 1884 and for railway motors in 1886.

As indicative of the recognition of the need, and of a willingness to develop, high potential operation I may be permitted to revert to the almost forgotten limbo of my early electrical railway prophecies at the Kansas City Electric Light Convention in February, 1890, where I gave the history of the Richmond railway, and essayed to expound the law and equity covering the adverse contentions of the trolley and telephone industries with regard to the use of the earth return. This was before the alternating current was dreamed of in connection with electric railway operation, not only for motors and working conductors but even for the prime transmission of energy, and I stated as follows:

"As regards the potential, other things being satisfactory, whatever pressure is demanded in the interests of economical and effective service will be used; and means will be found, consisting mainly in care of construction, which will make its use for the purpose, and as intended, safe and proper. We have in these matters to face the same questions as we have in the matter of steam pressure or of railway speed. To accomplish the larger engineering feats necessary to meet the demands of economy and commerce we will be governed more by the belief in our power to fully subordinate a good servant to our will than by our fears of its vagaries when allowed to become a master."

Illustrating at the same time the possibilities of d-c. electric operation between New York and Philadelphia, I gave a number of determinations of potential as affected by the number of stations and the use of a 2-wire system, or 3-wire one with the tracks as the neutral conductor, and showed that with a single station on the former plan that from 3600 to 4000 volts would be required. I said: "Can we handle it? Yes, in time, but perhaps not yet." And then I pointed out how the potential of the working conductor would be reduced to then certain possibilities.

In my inaugural address as President of this Institute on the "Coming Development of Electric Railways," at the Chicago Meeting, June 18, 1892, I enunciated certain laws showing the relation between distances, weight of copper and potentials. In speaking of the limits of potential, I pointed out that we were at that time, if using d-c. motors, practically limited to a difference of potential of from 1000 to 1200 volts, and that to go above that limit it would probably be necessary to put motors in series as I had sometime before proposed for long distance power transmission.

I also repeated the illustration which I had given at the Kansas Convention in 1890 showing the potential requirements on a possible electric service between New York and Philadelphia, and, pointing out that the potential indicated in a certain arrangement was less than 1000 volts, said:

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"I am not prepared to state that we may not use even a higher pressure, because I believe whatever is demanded in the interests of economy, all things being considered, will be used,"

although to keep within safe limits the centers of station supply should be multiplied so long as increase did not seriously effect the general expense of working.

In February, 1903, I had the honor of being appointed a member of the Electric Traction Commission of the N. Y. Central Railroad, and when the system of electrification was adopted in the following year, commercial developments had not progressed far enough to warrant general approval of an increase above the 650 volts then adopted. But I had not abated one jot my belief in the certainty of an increase, and in March of 1904, in an article on the Past, Present and Future of Electric Traction in the *Electric World and Engineer*, I said:

"While d-c. motors may always be somewhat at a disadvantage in the matter of individual potential, when there is a plurality of motors, as in the large locomotive, it is quite possible on a d-c. system to work up to 1700 or even 2000 volts on a single trolley line, maintaining a maximum as in regular use on the Berlin Elevated, of from 850 to 1000 volts on individual motors; and if a three-wire system be used it is quite possible to make use of a maximum trolley potential of nearly 4000 volts. I am not prepared to say yet that this is advisable, but it is possible, and I submit that in the problems involved in any trunk line development there are many questions of greater importance than that of the relative allowable trolley potentials for d-c. and a-c. equipments."

Shortly after, the beneficial results of the use of the interpole in stationary motor construction and operation had been, in my judgment, sufficiently demonstrated to warrant my recommending to manufacturers the adoption of this construction in their railway motors. It was soon my privilege to see the first test of such a motor, in consequence of which I urged the most rapid possible development of it, a departure which was for some time the subject of critical comment by trade rivals. After the success of 1200-volt operation was assured, in answer to a query of "what next?" I replied, "2400 volts, without question,"—for I was heartened anew in my convictions of the great possibilities of this new departure, and did not hesitate to commit myself to prophecies with regard to the then practicability of that rise in d-c. operation which I had so long advocated, and at a time when the most strenuous efforts were being made to promote the use of the single-phase motor for serious railway work to the exclusion of all other methods.

In a communication under date of September 14, 1905, on the subject of "Direct-Current Electric Traction at Higher Voltage" appearing in the *Engineering News*, I stated:

"I have long advocated, and am keenly alive to the economic bearing of increased potentials, however obtained, but also mindful of certain practical features which must be considered in connection with them.

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I believe, however, that where a-c. motor operation, with overhead construction, is adopted, there is but little reason for halting at any moderate limit, but that such potential should be used as may be necessary, all things considered, to get a reasonably full measure of the possible economy of investment.

On the other hand, I have frequently pointed out that the limits of d-c. operation are by no means reached, and 500 or 600 volts was an arbitrary standard which present possibilities in the construction of apparatus no longer warranted maintaining when leaving the field of tramways to take up the consideration of trunk line application.* * * *

I am prepared to engineer and carry to a successful conclusion a d-c. installation at a working pressure, even on a third rail, of not less than 1500 volts, which is at least two and half times that ordinarily used.

I believe it may be admitted that, although oftentimes having taken a somewhat radical and advanced position in electrical railway matters, I have never made a public proposal which I have not been ready when called upon to carry out; and should conditions arise warranting an equipment such as is proposed, I propose to establish a new and necessary comparative standard in equipment possibilities. And I venture, further, to affirm that 1500 volts is not the limit of practical d-c. operation.

On December 12, 1905, Charles H. Mudge, in a communication to the *Street Railway Journal* anent the New Haven installation, remarked:

"That the d-c. system has reached, or is anywhere near its final state of development, no consulting engineer would prophesy, and just at this time, when we are being presented with results and tests of 1500-volt d-c. railway motors and motors for 700-mile transmission projects, it would seem rather premature to consider 500 volts as the standard, or, as considered by some, 'the limit'."

At the meeting of the New York Railroad Club, March 16, 1906, on the occasion of the presentation of a paper by Mr. Lamme entitled, "Alternating-Current Electric Systems for Heavy Railway Service," I criticised the comparison of systems on the basis of an assumed arbitrary limit in d-c. potentials, stating:

"It is unfortunate—and to me seems unnecessary—to assume that operation by one general plan, and that by a specific method, is the only means of making effective advance in the general field which confronts us, and that in order to emphasize the good points of any particular system comparisons should be based on an assumed state of innocuous desuetude with regard to another.

Especially do I object to the assumption that past practise measures the limit of potential in d-c. operation. I have recently ventured to predict the raising of the d-c. standard for certain classes of work to at least 1500 volts, and I now repeat, without reserve, that not only is this increase possible with modified forms of construction, but tests have already been made which show its practicability; and this development is effected in part by the introduction of communicating poles, and along another line indicated by recent bi-polar developments also makes possible the

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resuscitation and adoption for locomotive use of early and effective methods of variable speed control, which become of special importance on roads with heavy grades."

A month later I ineffectually urged upon the engineers of the Washington, Baltimore and Annapolis line the adoption of 1200-volt d-c. operation, but received no support from either those engineers or the contractors for the equipment. The single-phase a-c. system was adopted, but with such disastrous results that after a loss of several hundred thousand dollars this system was changed over to direct current at the potential I had advised.

In the fall of the same year, I recommended to the consulting engineer of the Central California Traction Company the use of a 1200-volt d-c. third rail, as preferable for that particular installation to 600-volts d-c. or the single-phase a-c. system. My recommendation was adopted and the installation, the first of the kind, went ahead on this basis.

A month later I discussed quite fully the details of the 1200-volt operation with the consulting engineer of the Southern Pacific Railway Company, and successfully recommended this potential for the Oakland suburban lines of the Southern Pacific system. So doubtful, however, were the contractors who supplied the equipment that they hedged by using two 600-volt motors in series, for the avowed purpose of being able to fall back upon operation at the lower potential in case serious difficulties should arise.

In a discussion of Mr. Mayer's paper on "Steam versus Electric Operation of Trunk Lines" before the American Institute of Civil Engineers in Nov., 1906, I called attention to my statements of sixteen years earlier, and added:

"Since the date of the Kansas City Convention I have often advocated the necessity of higher potentials, and am glad to say that not alone in a-c. work, but in d-c. application, my early prophecies, repeated a year ago with an expression of readiness to undertake the responsibility of d-c. installation of 1500 volts, even on a third rail, have, by virtue of the developments of recent months now been brought within the range of practical accomplishment. This would mean an increase under ordinary trunk line conditions of fully five times the distance between substations common with 600 volts, and often even the possibility of their entire elimination."

At the same time I called attention to the fact that, comparing the condition of the art then and a couple of years earlier, three important and radical developments had taken place in d-c. motor construction, the first of which was the use of the commutating poles, which, with additional facilities in control, made perfectly possible the construction of d-c. motors at from 1200 to 1500 volts, with the further possibility of operating two in series at double potential.

Attention was called to the remarkable departure in the construction of the New York Central gearless locomotives, in

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which the hitherto invariable practise of maintaining the fixity of relation between the armature and the field magnet has been abandoned, and pointed out that this machine, adopted by the Electrical Terminal Commission of that road in the face of much ridicule, was a natural 1200-volt machine without commutating poles.

In the winter of 1906-7, after a personal inspection of the Sacramento Division of the Southern Pacific Railroad from Rockland to Sparks, I submitted a bid for the electrical equipment in competition with alternative bids on the single-phase a-c. system, to be operated with an initial potential of 1500 volts at the substation third rail junction, and described the possibilities of electrical braking, both direct and regenerative through the use of independently excited fields as is now used on the Chicago, Milwaukee and St. Paul equipment.

It is probably not generally remembered that in my experiments on the Manhattan Elevated in 1886 I used, for the field as well as armature, rheostatic control for speed variations, and also, for the first time in the art, regenerative as well as direct electrical braking on a plan described before the Boston Society of Arts in 1885.

In January, 1907, Messrs. Stillwell and Putnam read their paper on "Electric Motor versus Steam Locomotive," before the American Institute of Electrical Engineers, and urged the adoption of a 11,000-volt 15-cycle single-phase a-c. system as the standard for trunk lines, and as "the only class of equipment deserving serious consideration."

In the discussion of the paper the query was addressed primarily to me: "Where ten years from today will be the 1200-volt or the 1500-volt d-c. systems which have been suggested as substitutes for high potential alternating systems in heavy electric traction?"

I believe I then stated that the higher potential d-c. systems would still be here,—as they are,—the stepping stones of higher d-c. potentials, and also that operation at 1200 to 1500 volts by direct current had not been advanced by me as a substitute for high pressure alternating current for heavy electric traction, or as the only means available for this purpose, but that it had been advocated as one practical development along existing lines which, under many conditions and with the then development of the 25-cycle a-c. motor, offered some possibilities of railroad operation denied to the latter.

Some additional comments which characterized this discussion are appended.

"On many lines which can properly consider electrification, the higher voltage d-c. system, according to any present development, will give better results than the a-c. overhead system."—*Frank J. Sprague.*

"At that time (Sept. 1904, referring to an earlier paper) I said that I considered the heavy railway electrification of sufficient importance to warrant the use of a low frequency which is most suitable for such work,

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independently of any frequencies already in use. I will hold to that opinion."—*B. G. Lamme.*

"This paper is a prophecy. It is interesting to know that the fulfillment of the prophecy has already begun. One of the oldest railways in the country has proved itself the most progressive and has during this week put into commercial service an electric traction system which embodied most of the features which the others have assumed as probable characteristics of the standard of the future."—*O. S. Lyford, Jr.*

"That the three-phase a-c. locomotive is by far the most suitable engine for this purpose I believe to have demonstrated above."—*C. L. de Muralt.*

"There are not sufficient operating data and experience at our disposal to enable one type of motor and one system of distribution to stand above all others as possessing qualifications demanding its universal adoption, and, hence its standardization."—*A. H. Armstrong.*

"The whole question of the electrification of steam roads comes down to one of dollars and cents, and the system that can be operated and installed for the least money will be the one to be adopted.* * * * * * It is a question whether the problem can be solved by the simple d-c. system, which our friend, the father of electricity, loves so well, or whether we must go to something higher and nobler, and up with our voltage and up in the air with our trolley. Our experience is that the decision is generally in favor of the locomotive of the single-phase type. I have considered the single-phase locomotive and the three-phase locomotive prayerfully and carefully, but it does not seem to me that either one of these is the type of locomotive which will meet the requirements of the railways of the country. The d-c. locomotive as it has been designed certainly will not do it. * * * * * * A single-phase locomotive seems to offer the greatest possibilities."—*N. W. Storer.*

"I believe that the solution of the railroad problem is going to be by means of * * * * a high-voltage overhead trolley with a single-phase motor * * * * As a whole the system provides a better solution for trunk line electrification than any other in sight at the present time. I, for one, * * * * feel sure that nothing stands in the way of the standardization of this frequency."—*Wm. McClellan.*

"If the advocates of the d-c. system could bring forward apparatus that would operate and transmit at the same voltages that the a-c. system does, a great deal of this discussion would not have taken place."—*J. B. Whitehead.*

"Mr. Sprague is in favor of the d-c. system. He has done so much in the development and application of electric apparatus, first, by the d-c. motor and more recently by the multiple-unit system of control, that I should be very sorry to see him make a serious mistake, and I hope that before he nails his flag to the 1500-volt d-c. mast head he will take into account all the evidence presented tonight."—*L. B. Stillwell.*

"While in entire sympathy with every practical development, I care not by what means or along what lines, I have opposed, and will continue to oppose, any basis of comparison which assumes as worthy of the fullest credence any and every claim made for single-phase a-c. motors, while denying either the possibility, practicability or importance of the

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utmost development along d-c. lines, whether used for overhead or third rail construction."—*Frank J. Sprague.*

"With the principle initiated by Messrs. Stillwell and Putnam I am thoroughly and heartily in sympathy; but * * * * I believe we should only undertake standardization when we have something to standardize. The Institute would lay itself open to serious criticism if it should undertake, for example, to establish a standard frequency for electrical equipment of steam railroads when there is no single electrified steam road in this country operated by single-phase current."—*Calvert Townley.*

"It is not my intention to appear to condemn the entire single-phase system on the showing of one road, the operating costs of which have been investigated by me; nor is the fact that 1200-volt d-c. motors have been specified by me for a large suburban service to be taken as a declaration in favor of high-voltage direct current as a substitute for single-phase in all cases. The right is reserved to choose for each specific case the type of apparatus best adapted."—*A. H. Babcock.*

"Mr. Frank J. Sprague and possibly a few other engineers are inclined to believe that the high potential d-c. motor, for example, 1200 or 1500 volts, is preferable to the single-phase motor. Such advantages as the d-c. motor possesses in the general railway field disappear rapidly when we consider this field as a whole rather than regard special cases in which the reasons for electrification are so weighty as to overcome even the comparative possibilities of a system apparently limited to 1200 to 1500 volts.

For ourselves, the arguments in favor of the a-c. system are such as justify a setting aside of d-c. systems and concentration of effort in the prompt standardization and more rapid development of the alternating system."—*Stillwell and Putnam.*

In the *London Times and Engineering Supplement* of April 10th, 1907, Mr. H. M. Hobart in commenting upon Messrs. Stillwell and Putnam's paper on the substitution of electric motors for the steam locomotives, made a curiously exact prophecy as follows:

"My opinion is that within ten years, continuous current systems as applied to railway electrification will employ line pressure more of the nature of 2000 or 3000 volts, and these systems will, in all probability, have come into extended use. The single-phase delusion will meanwhile have been exposed, but at the expense of the capitalists, and the system discredited."

Four months later I had the honor of expanding my views in a paper entitled "Some Facts and Problems Bearing on Electric Trunk Line Operation," before this same Society, and perhaps I may be permitted to make two or three quotations to illustrate my then attitude, as follows:

"No one can deny that if the single-phase motor be developed to a high state of weight-efficiency, unhandicapped by excessive weight of the collateral apparatus necessary on a car to utilize it, and if the capacity of conductors, especially steel conductors, for alternating currents can by any discovery be raised, the elimination of moving machinery in, and the

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simplification of sub-stations would open up a very extended and important field for the use of this type of apparatus.

But with developments as they are at present, what is the actual field? As there is no general agreement as to methods of construction, so to, I find no fixed conclusions as to the field of commercial usefulness; rather on the contrary the sharpest differences of opinion. Some, with enthusiastic catholicity, make it all-embracing for steam roads, quite irrespective of well known limitations. Others, although at times seemingly contradictory, are even more elastic in their claims.

It seems to me that the present principal field of usefulness of the single-phase system is on roads of considerable extent which operate an irregular and sparse traffic, and where only a moderately expensive, or what may be called a second-class overhead construction, which will keep down the ratio of line investment to that of the balance of equipment, is tolerable. As one departs from this condition, adopts more permanent construction, and faces the problems of denser traffic and higher capacities, any advantages of the single-phase system will disappear, and the superiority of the d-c. equipment, with such improvements as are in sight, become manifest. But whatever may be the future of single-phase operations under the conditions stated, any present claim for it as the preferable equipment for congested service demanding high schedule and great capacity is not worth a moment's thought, for in this field, at least, it cannot touch the d-c. system.

There is at present no single system which can be selected as best for all purposes, but rather, that a wide and increasing use of each will be created, and in the majority of cases a compromise selection of the best elements of a-c. and d-c. practise will obtain.

I see no practical necessity to formulate conclusions by averaging conditions, and I cannot conceive the responsibile officers of any trunk line road being guided in their determination of what seems best for their own requirements by consideration of what some road thousands of miles removed in location, and enormously differing in operating conditions may do.

In any case, the most satisfactory system will be that one which will permit of continuous all-round operation under such conditions as will utilize to the utmost all the beneficial features of electric application. If any one system can be demonstrated to meet these conditions better than all others, then that system will become preeminent, no matter what standards may have been adopted or recommended, and no matter what our preconceived prejudices may be."

Among the comments upon this paper, I will instance but three typical ones:

"For trunk-line operation I have held and still hold the opinion that the 15-cycle a-c. single-phase system possesses inherent characteristics which, in this class of work, constitutes controlling advantages as compared with any d-c. system that has been suggested or is liable to be developed into an operative system. With this opinion the paper of this evening joins issue."—*L. B. Stillwell.*

"If it were not for the greater possibilities of the single-phase system, there is no doubt but that the high-voltage d-c. motor would be quite attractive. As it is, I believe that systems should be developed which

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offer the best solution for the entire railway problem. To attempt to develop a number of systems would result in not only scattering the energies of manufacturing companies, but would retard the ultimate solution and supply the railways with a heterogeneous collection of equipments that would postpone standardization for many years."—*N. W. Storer.*

"There is a class of service where a-c. motors are necessary—a long railway with infrequent and irregular service, and a considerable amount of fluctuating freight traffic—in short, conditions where synchronous converter sub-stations would show a poor load-factor. In such cases, d-c. operation appears impracticable, and here is the field for the a-c. motor or the steam locomotive."—*C. P. Steinmetz.*

Although nine years have passed since that presentation, I see no reason to change the general conclusions I expressed at that time.

In November, of the same year, in an article on "Electrification" in the *Railway Gazette* by Mr. H. M. Hobart, he suggested using as high as from 1200 to 1600 volts between third rail and traffic rail, and by operation on the three-wire system, using the rails as a neutral, a total of from 2400 to 3200 volts.

In January of 1909, as the consulting member of the Electrical Commission of the Southern Pacific road, I again recommended the use of electricity, but made the specific basis of comparison with steam operation direct current from a third rail with an initial potential of 1800 volts, the equivalent in distribution of nearly 3000 volts if supplied from a trolley.

This is the year 1916. For practically twenty years the potential for d-c. railways remained unchanged at 600 volts. In ten years it has jumped to 3000 volts on the Chicago, Milwaukee and St. Paul Railway, one of the typically most difficult, and embracing in its 437 miles of line more route mileage than all the trunk line electrifications in the world. The 11,000-volt 15-cycle "standard" is non-existent in this country, and not a single new phase railway motor is now installed here except on the few systems remaining.

Mr. Renshaw's paper seems to indicate an Armageddon. The advocates of systems who have lain so long in their trenches seem to have heard the bugle calls of advance and retreat. On which has long attrition told the most heavily, from whence have come the most effective reserves, to whom will be awarded the vantage? For myself it seems as if the long day of waiting has nearly ended, and that I can at least rest professionally content in some measure with the verdict which will finally be rendered.

William J. Davis, Jr.: I do not think the Southern Pacific electrification presents any new problems at all. The discussion to-night seems to be along the lines of increases in voltage far beyond those used on the Southern Pacific. The Southern Pacific electrification has been in operation about seven years, and the success of the installation has been very marked.

As regards the tendency to higher voltages, it would appear

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that the proper voltage to be chosen for a given installation would depend upon the maximum tonnage to be hauled and limitations as to speed. The tonnage capacity of a system is dependent, we may say, upon the number of tracks that are in service. In a single track road, if heavy tonnages are to be handled, it will be necessary to adopt higher voltages than would be necessary for a road having sufficient traffic to require two or three or possibly four tracks. In the case of a four-track road, all the tracks being in multiple, the drop in voltage in the track is greatly reduced, and we also obtain the advantage of the copper trolley wire or third rail for all four tracks in multiple, so that even when locomotives of very large powers are used, say 3000 or 4000 horse power it will be found in so far as the distribution system is concerned, that a moderate voltage, possibly 1200 or 1500, would prove as effective in handling the traffic as would 3000 volts, or more, in the case of a single track or double track road.

In a reduced number of tracks, some economy is gained in going to higher voltages, but the exact and most desirable voltage would depend not only on the saving in the amount of copper, but also on the load factor on the substations and the cost and number of locomotives required to handle the traffic.

In a single track freight road, it will be found that upon the basis of the weight of trains now in use, very little improvement in load factor is secured if the substations are placed more than thirty or thirty-five miles apart. With this spacing, the copper required for delivering 3000 or 4000 horse power to a train is not at all excessive at 3000 volts, and is fixed almost as much by mechanical reasons and current carrying capacity as by the desire to secure a low drop in voltage.

Substation capacity also as applying to the whole system is not materially reduced, for the reason that the synchronous converters and motor generator sets are usually designed to stand three times normal load for a short time, and so long as at least 33 per cent load-factor is secured there will be no saving in the total amount of substation apparatus.

The whole problem, therefore, appears to be narrowed down to the question as to the number of locomotives required on a given division and their cost. As a general rule, the cost of the locomotives required for handling the traffic of a single track road will amount to about one-third of the total cost of the electrification. If, therefore, there is a material increase in the cost of a 5000-volt locomotive as compared with one for 3000 volts, this increase in cost may prove the determining factor. In the case of the Milwaukee electrification, forty-two locomotives were required, and an increase in their cost of fifteen per cent, due to an increase in voltage, would exceed the total cost of feeder copper for the entire system as required for 3000 volts. In the case of a double track road in which the locomotives would be greatly increased in number, this difference would be still more marked, and would point to limitations of voltage possibly

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not exceeding 3000 volts as applying to most of the heavy freight traffic now obtaining on trunk line railroads.

William B. Potter: It is a pleasure to endorse much of what Mr. Renshaw has said as to the excellent features of high-voltage direct current. We are, however, rather more concerned with the future than with the past, and I think that the text of the ultimate is very well covered in his statement that: "The general limits upon which standard practise in any industry ordinarily settles are usually fixed by broad economic considerations rather than by physical limitations." He mentions as an illustration, that while it is possible to operate trains at higher speeds than the usual practise, it has not been found economically advisable to do so. I believe the question of higher d-c. voltages will be subject to the results of experience, and whether the limit will be 3000 or 5000 volts, or some other voltage, will ultimately be determined by "broad economic considerations."

In any railway electrification there are certain features which may be considered separately as parts of the general scheme. Under d-c. operation the initial cost, maintenance and depreciation of some of these features are but little affected by the operating voltage, while other features are so directly affected as to be a determining influence in the selection of voltage most favorable to economic results. The power station, high-tension transmission lines and track bonding are in the class of features first mentioned, and to a considerable extent, the substations as well. Sub-station equipment of established type generally increases in cost per kilowatt capacity with the increase in voltage for which it is designed; and while there would be fewer substations at higher voltages, the amount of included traffic usually becomes greater by reason of the longer distance between substations, and therefore there is little or no reduction in the total cost of substation equipment.

The two features principally affected by the choice of voltage are the secondary distribution copper, including contact conductors and the rolling stock. A careful study of the respective merits of 3000 and 5000 volts was made in connection with the Chicago, Milwaukee and St. Paul electrification. There appeared to be little difference in the initial cost as a whole, the reduction in copper at the higher voltage being offset by increased cost of the locomotives. On the basis of 3000 volts the relative value of the different features in respect to each other may be illustrated by the following percentages: the high-tension transmission line complete, about 10 per cent; track bonding, 4 per cent; substations complete, about 18 per cent; the overhead construction, feeder copper and trolley complete, about 28 per cent; and the locomotives about 40 per cent. The 3000-volt copper for feeders and trolley only being something less than 20 per cent, and the locomotives being about 40 per cent it is not surprising that the reduction in copper at 5000 volts would have been offset by greater cost of the locomotive.

Considering depreciation and maintenance, it is better that

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an equivalent expenditure should be in copper rather than in locomotives which require maintenance and upkeep. To economize in copper and pay an equal amount for more expensive locomotives would be a transaction on the wrong side of the balance sheet.

Mr. Renshaw's comment with respect to 2400 and 3000 volts is in the main well taken. The Butte, Anaconda and Pacific might well have been 3000 volts. Occasions may arise, however, where the use of developed apparatus may be utilized to advantage at some other voltage than that for which it was originally designed,—a case in point is an electrification requiring locomotives with the same tractive power as those used on the Milwaukee, but at a speed of 12 instead of 15 miles an hour. It would be unnecessary expense to redesign this equipment for lower speeds when the same equipment at 2400 volts will give the speed desired.

Within the requirements of railway motor design multiples of 750 volts seem to be about the higher practical limit for advantageous winding. For the speeds usually required it is about as easy to wind a motor for 1500 as it is for 1000 volts, therefor multiples of 600 or 750 volts as a maximum naturally fall into line as the preferred voltages for d-c. operation

Mr. Renshaw in advocating 5000 volts makes this comment,—"With practical apparatus for this voltage available, the problems of distributing and collecting the necessary power for the largest locomotive likely to be required can be readily solved, so that although further increases might be possible they should be entirely unnecessary." There is at present no necessity for 5000 volts to successfully handle the distribution and collection of the necessary power for the largest locomotive likely to be required. The collection of power for the Milwaukee locomotives at 3000 volts is a complete success, there being no sign of arcing at the contact between the pantagraph and the trolley wire in either freight or passenger service. Although the locomotives are equipped with two pantagraphs, a single one only is used; the current taken on the mountain grades being 800 to 1000 amperes, at 15 miles an hour by a single freight locomotive, and the same current at about 30 miles an hour in passenger service. The problem of successful current collection is greater at the higher speeds, and experimentally over 1500 amperes have been collected at over 60 miles an hour with a single pantagraph and no sign of arcing. The success on the Milwaukee is due both to the arrangement of the pantagraph collectors and method of supporting the contact conductor. Each pantagraph is provided with two collecting pans lined on the bearing surface with copper strips, and the contact conductor is two 4/0 copper wires which are in contact with each other in the same horizontal plane. The hangers supporting each of these contact conductors from the catenary are alternated so that the hanger of one conductor is midway the span of the other. The object of this arrangement of hangers being to minimize any inflexibility in the sup-

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port of the conductors. For the successful collection of current without arcing it is absolutely essential at all speeds that intimate contact be maintained between the pantagraph and the contact conductor, and this can best be accomplished by so supporting the conductors with loop hangers, allowing freedom of vertical movement without the added inertia of the catenary. The upward pressure of the pantagraph should further be sufficient to slightly lift the contact conductors. The contact conductors are, therefore, lifted and carried free of the supporting catenary by the pantagraph in its passage. We found through a series of tests, that the wear of the pantagraph collector and the contact conductor was due not so much to the friction or mechanical wear as it was to the arcing due to collecting current, even an incipient arcing, so small as to be hardly visible, having a destructive effect. As an illustration, when collecting 1000 amperes, the rate of wear with 20-lbs. pressure against the contact conductor was about double what it proved to be at 30 lbs. pressure, the latter being the pressure adopted for the Milwaukee service. Running copper to copper we found, as might have been expected, that lubrication of the contact surfaces was essential to maintaining a smooth surface, and for this purpose a mixture of grease and graphite was used. It might be expected that lubrication would increase resistance of the contact surface. The most careful examination seemed to indicate that the conductivity is rather improved than otherwise. So far as we can judge from the tests, and from other lines operating under similar but less favorable conditions, the contact conductor on the Milwaukee will last for a number of million pantagraph passes.

There is no doubt that substation and locomotive equipment of 5000 volts can be successfully operated. The substation equipment would not differ materially from a 3000-volt installation. The locomotive motors, however, because of the additional insulation required, and doubtless some change in the design would have less power for given size and weight, and in all probability, a greater number of motors would be required for a given service. The locomotive control equipment for 5000 volts seems to be principally a question of the additional space required for insulation and for the more extended arcing of the contactors. Experimental operation of the Butte, Anaconda and Pacific locomotives at 5000 volts gave opportunity of trying out the control devices under conditions approximating service operation. Arcing and flashovers at 3000 or 5000 volts are more startling, but seem to be even less destructive to the apparatus, than at 600 volts. The high voltage arc seems to spread over more surface with less local burning than at the lower voltage.

The results of operation on the Milwaukee have been extremely gratifying. Nothing has occurred in connection with the use of 3000 volts that might not well have happened with 600 volts. Minor troubles have developed in the auxiliary devices, particu-

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larly on the locomotives, which are more annoying than serious, and can easily be corrected.

The regenerative feature of the Milwaukee locomotives has in every way been as successful as anticipated. The eastern grade of the Rocky Mountains is 2 per cent for 20 miles, and both freight and passenger trains are taken down this grade without air brakes more steadily and smoothly than they run even on the level, and without the delay incident to inspection of brake shoes and wheels as required when air brakes are used. On the lesser grades, where an occasional application of air brakes has formerly been required, regeneration is also made use of to control the train at whatever speed desired. The flexibility of d-c. regeneration makes it particularly suitable for the regulation of trains over a variable profile.

I quite agree with Mr. Sprague that it would be unwise to say that 3000 volts is a finality, and having in mind the economic problems that have to be dealt with, and that railroads are operated for profit, there would be even less wisdom in the arbitrary establishment of a standard not based on experience.

Calvert Townley: I can endorse the last speaker's remarks against the establishment of a standard voltage or trying to say now what shall be the limitations of future practise. I believe that the Institute and all engineers individually should encourage every possible advance in the art, and developments such as the one described in Mr. Renshaw's paper clearly indicate that substantial progress is still being made. Every improvement in fundamentals even if accompanied by some unfavorable construction limitations which are not fundamental should be welcomed and encouraged.

In commenting on the necessity for looking at every problem from all angles when selecting a system, the last speaker quite properly favored a greater investment in the excess copper required by a lower voltage system and which depreciates very little, against the same amount put into the increased cost of the motors and auxiliaries of a higher voltage system where the maintenance and depreciation are both greater. It must be borne in mind, however, that a system which permits the use of a higher voltage scores a distinct fundamental and permanent advance in the art while whatever may be the present offsetting disabilities of increased equipment costs, these are largely temporary. We are just beginning to make 5000-volt equipments and 3000-volt equipments are not so very old. The history of all electrical development has shown that we may confidently expect improvements in design which will largely or entirely remove such temporary offsetting disabilities if any, as may now exist. One speaker cited the St. Paul Road as an example to prove that a 3000-volt trolley e.m.f. is high enough, concluding therefore that there is no use of trying to use higher pressures. He remarked that only one single 500,000 circular mill feeder is needed throughout the entire length of line. Without pausing to comment on the advisability of letting the entire service of

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a large railway system depend on one feeder it is interesting to note that a 500,000-circular mill bare copper feeder, 440 miles long, calls for over 3,500,000 pounds of copper, while with 5000 volts and with the same energy loss the investment in over 2,000,000 pounds of this copper would be unnecessary.

I feel very strongly that the Institute should welcome and in no sense attempt to decry any fundamental advance such as is described in the paper of the evening, and we should congratulate ourselves and the successful designers that such progress has been made possible.

While rejoicing at the recent rapid and marked increases in available continuous-current voltages, it is perhaps interesting to ask why this sudden activity—this very material advance after years of practically no progress when the limits seemed to have become rather firmly established? I find the answer largely in the increased demands of the new field of heavy railroad electrification and the development of the single-phase system which threatened to monopolize this field. The stimulus of competition has supplied the needed incentive to greater exertions in the study of continuous-current possibilities. If continuous-current apparatus was to receive serious consideration in heavy railroading it was necessary that every possible reduction in the excessive costs of that system should be made and every advantage taken of simplification of method. These conditions have not changed. It is still necessary for the continuous-current system to be bettered. A 3000-volt trolley is not good enough to more than incidentally share, much less to monopolize the heavy traction field against the alternating current. It is far from clear that even a 5000-volt trolley e.m.f. will be sufficient to prevail over available alternating-current systems but it is however a long step in the right direction and we should welcome and encourage it in every possible way.

S. I. Oesterreicher: While in Mr. Renshaw's paper only general outlines of the underlying fundamental principles of high-tension d-c. railway practise are discussed, perhaps, it will not be out of place to mention certain details of modern d-c. railroad practise.

Mr. Renshaw does not mention storage batteries in connection with high-tension d-c. railroad work. From this I infer, that Mr. Renshaw does not deem it practical to consider such, for the voltages which are discussed in his paper.

While there are, no doubt, considerable difficulties about a floating battery on a say 3000-volt equipment, however it certainly would be worth while to investigate these difficulties for the sake of the advantages gained from the economic operation of the installation as a whole.

The greatest handicaps for such a storage battery project are purely commercial. Naturally this side of the problem must be determined, from case to case as it is presented, and for which no definite rules can be set down in advance.

From the technical side there can be no question, that it is

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entirely feasible to build and operate with perfect reliability a storage battery for any reasonable moderately high-tension voltage.

To give this statement some weight, I will cite a 1100-volt d-c. railroad equipment as designed by Mr. Fischer, chief engineer of the Budapest City Railroad Co. This company operated in 1912 about 56 miles of three branch lines, having a total of about 124 miles of tracks.

On one of these lines, with a length of about 30 miles, there are one generating and two substations. Power is generated at 11,000 volts, 42 cycles, 3 phase, and supplied to motor generators in the substations. The generators in the substations generate on this particular line 1100 volts, d-c.

Upon the d-c. bus is connected a Tudor type 484-cell 1000-ampere-hr. battery which floats upon the system as any other standard battery.

There is nothing remarkable or special about this installation as a unit. The battery is standard in every respect, except the battery room, where the floors and wall are insulated from the building.

Even on a three wire installation, having as potentials 650 and 1100 volts, there is no difficulty experienced from the battery. The only special auxiliary in this double voltage equipment is the counter-e.m.f. booster regulator. This set consists of a 600-volt d-c. motor and six generators mounted upon the same shaft. The operation of this set is however standard. Each three generators taking care of one side of the system. The voltage regulation of the booster regulator as well as the load distribution between generator and battery is entirely automatic.

Another interesting feature of this Budapest system is the overhead line construction, with its flexible trolley wire suspension, upon the messenger cable. The trolley wire is allowed to slide lengthwise over the tracks, to adjust itself automatically to the climatic variations, allowing a free contraction or expansion of the wire without additional sagging under the suspension clamps, and from which it follows that sparking is almost entirely done away with. Counter-weights of about 3000 lb. at every mile or mile and a half or so about take care of the even trolley tension over their respective sections.

Benjamin F. Wood: I have been connected with a system that has standardization in fact, and lately I have changed to a system that had standardization, to a great extent, in theory. The trolley car man wants everybody to adopt his standard. I noticed in the first picture which was thrown on the screen that there were four or five voltages shown. It does seem that some standardization is desirable, but I think that the electrical man is getting himself into some difficulty with the railroad people when he talks about cost and the little refinements connected with the efficiency of operation. I made some calculations one time on the electrification of a double track line, 130 miles long, operating 3000 to 3500-ton trains,

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at twenty minute intervals throughout the day, at a maximum rating of 0.2 per cent, and found that could be done with 600 volts. The difference in cost between the different voltages was comparatively small, only 2 per cent on the total, and the cost of operation would be only a few per cent. When you realize that the total fuel cost on a trunk line is only five or six per cent of the operating expenses, and you have got to sell electric power to the steam railroad at approximately the cost of fuel when you take over that operation by electric service, you will see that when you come to save five per cent, or ten per cent, even, of this fuel percentage, it is of trifling importance when compared with dependability of operation. That is the primary thing. The railroad man wants something he can be sure is going to operate continuously and reliably, and that is the end to which all efforts at standardization should be directed.

Ernest V. Pannell: If I have understood Mr. Renshaw's conclusions correctly, he is strongly in favor of the motor, insulated for 1200 volts and commutating only 600 as opposed to the motor which operates at a terminal pressure of 1200. Now this operation of two motors in series on a 1200-volt trolley has always seemed to me to represent only half a solution of the high-voltage railway problem. It is expedient where a considerable proportion of the running is on the 600-volt trolley but one usually finds that where interurban cars operate within city limits, the switch over from 600 to 1200 volts occurs at the end of the limited speed area so that the motors take up full speed just as soon as full speed is permissible.

The main problems attaching to the design of high-voltage motors are two; those of insulation and commutation. In constructing a motor which will operate in series with another on 1200 volts, the first problem has to be met. Clearances have to be sufficient to take care of flashover, projections in the interior have to be rounded off and extra slot insulation carried. In a recent instance the slot space factor of a 150-kw., 1200-volt motor worked out at 37.5 per cent whereas the corresponding 600-volt design would probably have a value of 50 per cent; in other words an armature of given size has a capacity 25 per cent lower when insulated for 1200 as compared with 600 volts. Now in making the additional modifications for running the motor direct on 1200 volts the commutator bars have to be increased in number, possibly by 100 per cent and the armature, if a two-turn winding reduced to one turn. Simultaneously however the amperes per motor for a given output are reduced by some 50 per cent this makes it possible to shorten up the commutator by a similar proportion. Although on account of the space required for bearings, fan, etc., it is impossible to add to the core-length every inch saved on the commutator, it will usually be found practicable to increase the core by two to four inches and by this means the armature will carry a greater flux. On the foregoing basis therefore, a motor of given weight will actually have a greater output with 1200 terminal volts

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than where it is one of a pair designed for working in series on this potential.

As Mr. Renshaw implies, the question of dollars and cents will ultimately settle the maximum voltages for railway operation. We do not run our trains at ninety miles an hour because the cost of track maintenance and power for operation would be prohibitive. Similarly an economical maximum voltage will be evolved beyond which the extra cost and maintenance of the equipment will outbalance the economy on the line copper. Because 1500 volts is about the maximum which can be applied to a railway motor commutator in service with reasonably satisfactory results I would set the maximum desirable trolley pressure at 3000 volts in the present stage of the art.

A H. Armstrong: There are two rather positive statements made in Mr. Renshaw's paper and to bring them freshly to mind I will quote. With reference to the use of 2400 volts the author states "From a general standpoint, however, while the results have been welcome as a contribution to the development of the art, suitable applications for this particular voltage are apparently somewhat lacking." On the next page the author goes on to state, "For heavy traction on the other hand this voltage is much too low to solve the problem in a sufficiently comprehensive way to attract the investment of capital in electrification. Even 3000 volts, while overcoming the latter disadvantage to some extent, does not do so completely." The author then goes on to make the suggestion that 5000 volts direct current be adopted and standardized as the proper d-c. voltage for electrification work.

A number of years ago on the floor of this Institute the suggestion was made to standardize the 15-cycle a-c. single-phase motor system as the standard equipment for steam railway electrifications. At that time not a single 15-cycle a-c. motor was in operation in this country, and but one installation has been made in the many years which have since passed. Tonight we have the suggestion that 5000 volts direct current be standardized although there is only one experimental car equipped with 5000-volt d-c. apparatus which has been in intermittent experimental service for a period of a few months.

There are in operation in this country three very extensive railway systems using d-c. motor equipments of 2400 to 3000 volts, and contracts have been let for similar apparatus for two other installations also of some magnitude. In view of these facts it therefore seems pertinent to approach the proposal to standardize 5000-volt d-c. apparatus by asking two questions.

1. What facts are behind the two statements made by Mr. Renshaw in which he broadly discredits 2400 and 3000-volt apparatus as being applicable to main line electrification?

2. What experience is behind the suggestion that 5000 volts be adopted as a standard d-c. potential and what advantages does it offer?

The sweeping statements that 2400 and 3000 volts direct

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current "are much too low to solve the problem," cannot be accepted without advancing sufficient facts to disprove the economic fitness of the apparatus now operating successfully on three railways and under construction for two more. Especially is this so when one electrification at 3000 volts has a route mileage greater than the combined length of all the electrification thus far completed in this country to date. It is therefore impossible to let go unchallenged the broad statement that potentials considerably higher than 3000 volts direct current must be resorted to in order "to attract the investment of capital in electrification." In the absence of any facts supporting the claim that 3000-volt d-c. locomotives cannot successfully meet the requirements of heavy traction service, it is not out of place to refer to some of the fundamental features of the C. M. and S. P. electrification operating at that potential.

This electrification extends over four steam engine divisions, a total of 440 route miles across three mountain ranges, the Belt, Rocky and Bitter Root mountains, and presents all the problems confronting operation over a broken profile from level track to long sustained grades of 2 per cent. This 440 miles of track is fed from 14 motor-generator substations having an aggregate installed capacity of 59,500 kw. full load rating. In each of these substations there is one motor-generator set serving as a complete spare so that in normal operation of the road the aggregate substation capacity running is limited to 33,000 kw. The total d-c. load on the 14 substations will probably be less than 14,000 kw., giving a load factor of over 40 per cent of the aggregate running capacity of the substations. This remarkably high load factor is secured by spacing the substations some 32 miles apart as permitted by trolley distribution at 3000 volts direct current. This substation spacing is obtained in most cases with only one 500,000-circular mil feeder reinforcing the two 4/0 contact trolley wires, the exceptions being the 2 per cent grade over the Rocky Mountains and the 1.7 per cent grade over the Bitter Root Mountains, in which locations 1,400,000-circular mil and 1,000,000-circular mil feeder cables respectively reinforce the trolley.

We have then in the St. Paul electrification a good example of what can be done with 3000-volt trolley distribution and the above statement gives evidence that substation spacing is approximately 32 miles, the feeder copper installed is entirely reasonable and furthermore the load factor of the motor generator sets running in the substations under normal service is very good indeed. Furthermore, the 33,000 kw. running in the 14 substations furnish power to 42 main line locomotives and 2 switch engines having a combined continuous rating of 127,000 h.p. or 95,000 kw. which is further proof that the substation spacing is sufficiently great to profit to a large extent in the matter of diversity factor of the several locomotives operating and assigned to each division. A statement of the Butte, Anaconda and Pacific Railway operating at 2400 volts direct current would

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add further facts to those cited in the case of the C. M. and S. P. and these facts are submitted as substantial evidence that 2400 and 3000-volt direct current are sufficiently high to adequately take care of the demands of main trunk line electrification. The train weight on the St. Paul totals 3500 tons gross including locomotives, and these heavy trains operate against a 2 per cent grade at 15 miles per hour. On the Butte, Anaconda and Pacific trains of 5000 tons gross are being operated against a lesser gradient and the average drop in trolley feeders and ground return on either road will be found to be less than 10 per cent under the average traffic demands and possibly 20 per cent maximum under certain conditions of operation.

It may seem attractive to always consider the use of still higher voltages, but it must be recognized that very high voltages impose their burden of expense and complications upon the motive power and substation apparatus until a point is reached where these costs become so excessive as to more than offset the reduction in feeder copper and other advantages of a high distributing voltage. There is nothing inherently inexpensive in a high-voltage locomotive and there is little saving in the first cost of the entire installation by transferring a certain portion of the initial investment in copper to a corresponding increase in the cost of locomotives which is the result of going to higher potentials.

Referring again to the proposal to standardize 5000 volts direct current, I do not share with Mr. Renshaw the conclusion that this potential is a natural selection or in any way represents the last word in the development of d-c. locomotive equipment. Before the decision was made to adopt 3000-volt d-c. apparatus for the C. M. and S. P., exhaustive experiments were carried out at Schenectady with d-c. apparatus operating as high as 6000 volts with an idea of determining if possible the limiting potential of d-c. apparatus. No such limits were discovered, as with the hastily constructed apparatus tested, it was found possible to successfully open 6000 volts on contactors, circuit breakers and fuses assembled for the purpose and furthermore the current used was obtained from motor generator sets and was of sufficient volume to demonstrate the successful operation of d-c. apparatus at this potential in commercial service. To my mind therefore it is not a question of the feasibility of operating d-c. equipment at higher than 3000 volts, but rather what advantage either in first cost, cost of operation or increased facilities does the adoption of a higher potential offer.

The 5000-volt car fed from a mercury rectifier tube referred to by Mr. Renshaw constitutes a most interesting experiment but in no way forms a sufficiently solid basis for a recommendation to adopt 5000 volts direct current for heavy traction electrification. If facts can be disclosed which will discredit 2400 and 3000 volts direct current then it will be time to consider the initial installation of d-c. apparatus at a higher potential, and its successful performance perhaps in time may lead to the

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adoption of a general standard d-c. potential higher than 3000 volts. With the facts at hand, however, I see no reason to go to a higher potential than 3000 volts even to meet the requirements of the heaviest kind of trunk line service. In fact there is much more reason to suggest standardizing this potential with the weight of experience behind it than to blindly adopt a higher potential not yet in commercial service on any scale commensurate with the problems to be solved.

Selby Haar (by letter): I should like to have Mr. Renshaw give his reasons for preferring 5000 volts as the standard. Viewed as a multiple of 1200 and 2400 volts it should, apparently, suit him less than 6000 volts, which is derived from 1500 and 3000 volts. Furthermore I do not see that it is obtained by rectification of a-c. voltage or potential any more conveniently than some other potential of the same order of magnitude.

Carl Schwartz (by letter): Mr. Renshaw's paper in calling attention to the successful application for railway operation of direct current of sufficient voltage to compare in ecomony of transmission favorably with single-phase alternating current suggests a potential of 5000 volts as a standard operating voltage.

Without desiring in any way to detract from the value of standardization, I would like to caution against prematurely adopting a standard high d-c. voltage for railway work.

We have in operation a variety of systems with different pressures so that the ultimate loss on account of lack of standardization should not be materially increased if standardization was deferred until we are able to foresee more definitely what the future will bring us in new developments and experience.

Practically all standards are the result of gradual development to a degree where a further increase in perfection or efficiency is either impossible or unnecessary and it seems questionable whether we have reached this point as far as voltage for electric train operation is concerned. Standardization if adopted too early either means a check in progress or if progress is not stopped standardization automatically fails.

The paper further permits the conclusion that if high voltage direct current is as successful as it promises to be, the future standard system, if such a thing is possible, has increased chances to be direct current rather than single-phase alternating current.

The writer has refrained from taking part in discussions concerning the relative merits of single-phase alternating current as compared with direct current for electric traction. There is one feature in his mind, however, for many years and that is the difficulties connected with the generation of single-phase alternating current. These difficulties are usually reflected by appreciably higher cost of current and greater chance of disturbances in the generating station.

If these difficulties can be eliminated by the use of direct current, still retaining essentially the advantages of single-phase a-c. transmission, a long step in advance will be made.

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The principal reason for the relatively limited electrification of steam railroads is not that steam railroad men have failed to appreciate the advantages of electric operation but rather the fact that so far the investment required for all of the electric traction systems has been so high that it was in most cases hopeless to expect a saving in operating expenses to pay for the additional fixed charges.

Mr. Renshaw's paper indicates that this handicap shows signs of becoming materially reduced.

N. W. Storer: The point in Mr. Renshaw's paper that should appeal most to the railway engineer is the portrayal of the great progress that has been made in the car and locomotive equipments for operation on increasingly high d-c. voltages, culminating in the 5000-volt car equipment that has been in operation during the past year at Jackson, Mich. The operation of this equipment has been a revelation to all concerned and it may be interesting to discuss briefly the main points of interest in it, even though it has been partially described in the technical papers.

The development of this equipment was carried out in pursuance of a settled determination to find, if possible, a limit to d-c. voltage for railway purposes, or at least to see if it is possible to arrive at one which would be high enough to meet the requirements of heavy electric traction in extreme instances, and to do this economically. The development of 5000-volt apparatus was started several years ago at a time when 2400 volts was the maximum d-c. potential that had been installed on any line in this country. It was known that an experimental line was in operation in England at 3500 volts, d-c., but no information concerning it was available at that time. Since then, I have had the pleasure of riding on this 3500-volt car and have inspected the equipment. Owing to limitations in the substation generator, the equipment has been operated most of the time with the motors all in series giving half voltage and half speed. However, the commutation of these motors was excellent at full voltage and practically no trouble had been experienced with any part of the equipment, except the dynamotor which was used for furnishing power for lights, control and compressor.

This experience corresponds closely with that of the 5000-volt equipment, except that the latter has no dynamotor.

Any system of electrification, or any voltage that is applied to the electrification of a heavy traction line, should be suitable not only for locomotives, but for multiple unit cars as well. Since the 5000-volt equipment, which has been in operation, consists of four motors of only 100 h. p. each, this can be safely said to be suitable for multiple unit car operation. In view of the fact that many of the limitations to the voltage of a small motor are much greater than in a large motor, it would appear that it would be still easier to build larger equipments and loco-

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motives, at least the problems of insulation and commutation should be easier.

From Mr. Armstrong's discussion, it may be inferred that he thinks this is a freak construction. Certainly, the designs of the motor and switch groups are quite different from the ordinary types of motors and switch groups for car purposes. However, a careful examination of the equipment will show that the principles are identical with those of the standard well-known types and that the difference is in appearance only; the voltage between commutator bars is no higher than on the ordinary 600-volt motors; the voltages between the upper and lower layers of the armature winding are no greater than with any 1200-volt armature; the number of field coils is less than on the ordinary four-pole moter; in fact, throughout practically the entire motor, the construction is simpler than that of the ordinary 600-volt motor. Practically all that has to be given special care is the insulation of the armature windings from ground. How well this was done may be inferred from the fact that after the car had run over 30,000 miles, one of the armature leads, leading from the coil to the commutator bar, broke off and a hole about 1½ inches in diameter was burned through the armature hood. This armature stood a test of 12,000 volts a-c. to ground without a sign of distress. The commutation has been as near perfect as that of any 600-volt motor, and while there have been cases of flashing in the motor, they have, without exception, been due to abnormal causes, such as reversed commutating fields or broken brush holder cable, and in no case has there been any damage resulting from this.

The operation of the switches with the arc splitters has been so successful that there appears to be no difficulty whatever in designing switches to handle any reasonable amount of power at this voltage. The arc splitters serve to greatly increase the length of the arc, as well as to chill it. The insulation of the switch group was so perfect that although the switch group frames were grounded to the car structure, there was no case of a breakdown in the insulation until after a 44,000-volt transmission line had dropped on the trolley wire. Then a short time later, one switch insulator and one motor armature were grounded.

The auxiliaries are very well taken care of by the storage battery, which is connected between the main motors and rail. Since the operation of the compressor is delayed until the car starts, the battery is not required to furnish very much of the power for the compressor motor which operates from the current through the main motors. The battery absorbs the excess or furnishes any current that is required above the main motor current. The duty on the storage battery is, therefore, very light. Test on this equipment shows beyond question the possibility of operating satisfactorily with 5000 volts in light service. There would appear to be no reason to doubt that it will operate at least as well in heavy service.

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As to the question of standardization, I do not think that we need to feel that Mr. Renshaw had any intention whatever of starting out to show that 5000 volts could be at once adopted as a standard. It is a point to aim at, and it certainly seems more logical to undertake the development of apparatus for a voltage which it is recognized would be high enough to handle any kind of traffic with a very economical distribution system, than to proceed by the small steps which have thus far been made. As a matter of fact, it is recognized that 5000 volts would not be at all suitable for standardization if it could not be made thoroughly reliable. It has not, of course, yet received a test under conditions which would warrant adopting it for general use, or to replace other established systems, but it is certain that a new " bogie " has been established, and it is a voltage beyond which it appears scarcely worth while at this time to go. To be sure, this same equipment was operated at as high as 7000 volts experimentally with entire satisfaction, but this simply shows the factor of safety which the present equipment has.

There has been some doubt expressed by several of the speakers as to the economy of any higher voltage than 3000. The answer to this question depends solely on the cost of substations and locomotives. If the increase in the cost of locomotives is going to be a large percentage of the cost of 3000-volt locomotives, the limit would be very soon reached, but this depends entirely on the type of locomotive that is adopted, and the use of the twin armature bi-polar motor places a very different light on this question of cost from what would appear with the older forms of motors. As a matter of fact, it appears that the additional cost of a locomotive designed for 5000 volts over that for 3000 volts will be a very small percentage of the total cost, while the decrease in the cost of substation and feeder copper will be a very considerable proportion. It, therefore, seems inevitable that a higher voltage than 3000 will be utilized in the near future, and whether this voltage will be 5000, 4200 or 6000, is, to a certain extent, immaterial.

The advantage of a standard which can be adopted by universal consent is so great that I feel that every effort should be made to reach one at the earliest possible date. If we can get together and decide on something which we feel will be proper and fundamental, as Mr. Townley has expressed it, we will be doing far better than by trying so many steps along the line.

In a paper which I recently presented in England, I stated that in a country where there is an autocratic government, one man can decide on what is going to be the standard. In another country, where there is absolute independence and individual initiative, there may be a hundred different things proposed and used to accomplish the same purpose. In the first case while the man may not decide on the best system, it would probably nevertheless operate more satisfactorily than in the latter

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case where there are so many different schemes, because the cost of manufacture in the first case will be very much less and everyone will become familiar with the one system and kind of apparatus, and the operation will undoubtedly become satisfactory even though there may be some other system which would have been a little cheaper under the same conditions. At present, we are required to design apparatus to meet many different systems which are really intended to perform the same work. In this way, the cost of development and manufacture runs up to an enormous figure, which the operating companies must eventually pay for.

Mr. Sprague has, as usual, given a spicy addition to the discussion of the paper, although one must search a long time before finding wherein it applies to the subject under discussion. It would appear that he assumes from the fact that Mr. Renshaw, who represents the company which has been responsible for practically all of the successful single-phase installations in this country, has presented a paper outlining the possibilities of high-voltage d-c. apparatus, that the single-phase system is, therefore, dead. A little further investigation of the question will prove to Mr. Sprague's satisfaction that the single-phase system is very much alive.

Mr. Sprague has quoted one of my previous statements in regard to the influence of cost on the system of electrification. I still hold that the ultimate decision will be based on the first cost and the cost of operation, provided the systems are equally reliable. It is certain that reliability is going to be a prime factor, but reliability is a relative term. There are many things on a railroad which cause delays to traffic. If the number of delays incident to matters entirely apart from the power system is very large in comparison with the number due to the electrical equipment, the question of reliability of the latter becomes of less importance. 600-volt apparatus would doubtless be more reliable than any of the so-called high-voltage or single-phase systems, but the value of the small additional reliability would be far less than the extra cost of electrifying a long line with this voltage.

C. Renshaw: Mr. Sprague's principal point of disagreement, if I understand him rightly is that my simile was somewhat overdrawn, when I asserted that it was practically a universal belief, ten years ago, that 600 volts was the maximum d-c. railway potential, since even at that time he had predicted some of the things which have now come to pass. Aside from this minor point, however, I judge from his remarks that he agrees substantially with the ideas I have expressed.

Mr. Davis points out that with a given train unit the problem of distribution is simplified as the number of tracks increase. A certain minimum size of trolley wire must be used over each track for mechanical strength and with two or three or four tracks, the combined conductivity of the several trolley wires

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and of the various rails in parallel necessitates a less amount of auxiliary feeder than if only a single track were electrified. Stated in another way, with a fixed amount of auxiliary feeder, the greater the number of tracks the lower the voltage which can be used with a given economy of distribution.

While it might be inferred from Mr. Davis's remarks that in view of these facts, he would advocate selecting the voltage for any given electrification according to such circumstances and thus perhaps using 1200 volts in one case, 1500 volts in the next, 2400 volts in a third, 3000 volts in a fourth, etc., I believe that he merely wished to call attention to the principle rather than to advocate such a multiplicity of voltages for future heavy electrifications.

Mr. Davis states also, that since motor-generator sets and synchronous converters are usually designed to stand three times normal load for short periods, there will be no saving in the total amount of substation apparatus by increasing the load factor beyond 33 per cent. This analysis, however, overlooks the fact that the machines which have been designed to stand three times normal load have been made in this way to suit the loads which they must carry and not because such designs give the most desirable or the least expensive machines.

Finally, Mr. Davis states that as a rule the cost of the locomotives for any given electrification will approximate one-third of the total cost and that if there is a material increase in the cost per locomotive for a higher voltage as compared with a lower one, this increase might prove the determining factor. This fact is so obviously true that I thought it unnecessary to mention it. The cost of equipments for 1200 volts, however, is but little more than that of similar ones for 600 volts. Presumably, also, the cost of locomotives for 3000 volts has not proved materially greater than that of equivalent ones for 2400 volts. It seems probable from careful estimates that in view of the improved types of construction that are available, locomotives for 5000 volts can be built so as to cost but little more than if made for 3000 volts, and all of the statements in the paper with regard to the use of 5000 volts have been based upon this idea.

Mr. Potter agrees that my comments on the unfortunate circumstances that have given us electrifications at *both* 2400 and 3000 volts are in the main well taken, and this broad-minded position on the part of a man of Mr. Potter's ability and attainments is the most hopeful sign in the entire discussion. With this point appreciated, everyone must surely see the desirability in future of avoiding similar multiplications of voltages as far as possible, and as it was to point out this fact that the paper was primarily written, I feel decidedly encouraged by this statement from Mr. Potter.

Mr. Potter suggests a change in the last sentence of the paper where I said that if 5000-volt apparatus were "commercially

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available" such and such would be the case. He suggests the words "commercially economic," instead of commercially available. Such a change, however, would not in any way affect the meaning which I intended the sentence to convey, for to my mind, the apparatus which is out of line is cost, is not commercially available.

Another portion of Mr. Potter's remarks which appealed particularly to me was that in regard to the collection of current. After saying that this had seemed to be a great problem and that some years of study had been given to it, he adds "The solution was found to be rather simpler than anticipated." This sentence appealed to me because I believe that some day I will have the pleasure of hearing Mr. Potter, and some of the other gentlemen who have commented upon the paper, use these same words in regard to the employment of apparatus for 5000-volt direct current and the standardization of voltages for heavy electric traction.

Mr. Townley agrees that a potential of 3000 volts is not high enough to hold the field of heavy electric traction but he is not sure that even 5000 volts will do this. He announces, also, that he is against standardization, seemingly because he believes standardization tends to discourage advances in the art.

With regard to the last idea it seems to me that just the opposite is true. Nothing tends to encourage the development of an industry so much as a semi-permanence and general interchangeability of the apparatus for carrying it on, and no class of apparatus can be really developed on a commercial basis unless its use for a reasonable term of years is assured. I believe therefore that it would be much more encouraging to the art of heavy electric railroading if, instead of employing a little higher voltage in each successive case, where d-c. apparatus is used, some definite voltage, sufficiently high to meet all reasonable requirements, were generally recognized as being standard.

Replying to Mr. Oesterreicher, I had not mentioned storage batteries in connection with high-voltage d-c. roads, since as far as I know it has never as yet been necessary to consider their use seriously on such roads in America. I see no reason, however, why batteries could not be arranged for 5000-volt direct current if this were necessary.

Mr. Wood has made a good point by indicating that it is not so much the *cost* of electrical apparatus as its *worth* which concerns the railroad man, since the cost of the electrical part of the system is a comparatively small part of the total. "The railroad man", he says, "wants something he can be sure is going to operate continuously and reliably and that is the end to which all efforts at standardization should be directed."

It is obvious that if the skill of the various available designers can be constantly applied to perfecting the details of any given apparatus, rather than to changing its fundamental character, the results Mr. Wood is looking for are more likely to be secured.

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If the railroad man, also, is offered something that is already in use he can be much more certain of the results he will obtain. I believe Mr. Wood's remarks therefore are strongly in favor of the policy I have been advocating, of choosing the right thing for any given class of work as quickly as possible and then sticking to it.

Mr. Pannell, in advocating the use of motors wound directly for 1200 volts rather than of two 600-volt motors in series, in cases where the cars are not required to run at full speed on 600 volts over part of their route, has overlooked one important fact. Where a manufacturer builds motors for operating on 600 volts, as well as for 1200 volts, a considerable investment in drawings, patterns, tools, etc., can be saved by the use of the same motors with minor changes for the two voltages, instead of radically different designs. In arguing that 1500 volts is about the maximum potential which can be applied to a railway motor commutator in service and that to allow not more than two motors in series he would therefore set the maximum trolley potential at 3000 volts, he has apparently forgotten the double armature motor which Mr. Storer described and which with 1500 volts per commutator and two motors in series would permit a trolley voltage of 6000.

Mr. Haar inquires why the particular voltage of 5000 was chosen, since it is not a direct multiple of 600, 1200, or 1500. In undertaking to produce d-c. apparatus for a voltage high enough to be suitable as a standard for a reasonable period of years, we started to design our apparatus for 4800 volts, or double the value of 2400 volts, then the maximum contemplated. This was later raised to 5000, however, since it had a more euphonious sound than 4800. As a matter of fact our experimental line has been operated at about 5300 volts and the apparatus was tried on the test track with voltages up to 7000.

I am not particularly concerned with the exact value of the voltage chosen, whether this be called 4800, 5000, 5500, or 6000, since by the term "5000 volts" in the paper, I have intended to include anything in this range. The fundamental point which I have been trying to make, is that *some* voltage in the neighborhood of 5000 should be generally recognized as a standard for heavy electric traction so that d-c. electrifications can be installed with some degree of uniformity, instead of on a basis which will give each one a voltage just enough higher than its predecessor to be different without being sufficiently high to be adhered to in the next case.

Mr. Schwartz is apparently possessed by the same fear which Mr. Townley has expressed, that standardization tends to limit progress. I believe I have covered his points sufficiently in replying to Mr. Townley's remarks.

In referring to the discussion presented by Mr. Armstrong the first thing to be done is to free oneself from the confusion created by his way of grouping 2400 and 3000 volts together as

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though they were one and the same, instead of being different systems, sufficiently far apart to be entirely distinct and yet so close together that, as emphasized by Mr. Potter, it is unfortunate that we have both of them. Taking up his question, then, as to what has discredited these two systems for heavy electric traction, I would reply that as far as the 2400-volt system is concerned, Mr. Armstrong himself discredited it by ruthlessly abandoning it in favor of 3000 volts when the first real railroad was presented to him for electrification.

As to the 3000-volt system, nothing has as yet "discredited" it. The St. Paul electrification at 3000 volts is a magnificent piece of work, but so is the New York Central electrification at 650 volts, and there is no more reason to suppose now that the former represents the magic limit of voltage for minimum cost than there was a few years ago to suppose the same thing about the New York Central. I believe, in fact, that if Mr. Sprague would hunt up the bibliography with even a small part of the assiduity he has used in preparing his discussion, he could show that only a few years ago Mr. Armstrong himself was just as positive that the 650-volt system was the only rational way to electrify a railroad, as he now is that there is no possible reason for using more than 3000 volts. I have great hopes, therefore, that Mr. Armstrong will keep on raising his voltage and that if we give him sufficient time, it will sooner or later reach 5000. I will hence waste no effort in trying to convince him now.

While it is true that the operation of one 400-h. p. car for 35,000 miles constitutes the sole commercial experience with 5000-volt direct current, this is a much greater experience than was available when the first line was built to operate at a voltage of 1200 instead of 600, or when the first electrification was undertaken using 2400 volts instead of 1200. From this standpoint, therefore, the matter seems in reasonably good shape.

"It may seem attractive", says Mr. Armstrong, "to always consider the use of still higher voltages" but to me it decidedly does not seem attractive and it is in the effort to set others thinking of the obvious disadvantage of such a procedure that all of my energies have been directed. In the period referred to in the beginning of the paper, 600 volts was the established standard for electric railways, so that "an electric railway" meant a 600-volt d-c. electric railway. This particular standardization on 600-volt direct current, was not brought about by action of the A. I. E. E., or any similar body, but by general recognition of the merits of the case by manufacturers and users of the apparatus. It was nevertheless very effective. When it was proposed to build or equip a given line in those days there was no question as to voltage, or system, to confuse the main issue of whether the work should or should not be undertaken, and it was during this period that most of our present city and interurban railways were built.

To establish the same conditions in the field of heavy traction

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at this time, is of course a much more difficult matter, but there is no question that the advantage to all concerned would be equally great could this be done. It is not my idea that such a standardization could be brought about by any resolution or recommendation of the Institute, and in suggesting the adoption of a standard I had no such action in mind. If standardization comes, it must be by a general consensus of opinion, as in the case of 600 volts, and my real object has been to start such an idea.

Most of the speakers who took part in the discussions seem to have allowed themselves to be misled by the difficulty of the problem. Not seeing any way to bring about such a standardization of voltage immediately, they have felt forced to speak against the necessity or the desirability of it. No great work is ever accomplished, however, without a great deal of thought and planning and dreaming long in advance of the realization, and if I have succeeded in starting some of this thought or planning or dreaming, I will feel that the first steps have been taken.

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INDUCTIVE INTERFERENCE AS A PRACTICAL PROBLEM

BY A. H. GRISWOLD AND R. W. MASTICK

ABSTRACT OF PAPER

In this paper are given a review of the factors which affect inductive interference in telephone circuits from high voltage power transmission circuits, a presentation of the practical considerations regarding the reduction of the interference, and a description of actual cases of the application of these means of reduction.

Distinction is made between the effect of balanced and of residual voltages and currents on the power circuit and between the effect of voltages induced between the wires and those induced between wires and ground.

The wave shapes of the voltages and currents in the power circuits have a very important effect in the amount of inductive interference in telephone circuits. The precision of the electrical balance of the power circuit is also important because of the relatively very large effects of unbalanced voltages and currents in producing inductive interference.

A discussion is given of the principles to be used in the design of coordinated transposition schemes for power circuits and telephone circuits which parallel each other, and schemes are described which have been devised for application to the telephone circuits in order to simplify the design of transpositions in the power circuits which make it possible to balance the induced voltages.

A detailed discussion is given of three particular cases of parallels showing the application to them of the different methods by which inductive interference can be reduced. In the Appendix is an outline of information regarding parallels intended to facilitate the determination of the remedial measures desirable in any given case for reducing inductive interference.

THE discussions of the subject of Inductive Interference hitherto presented before the Institute and in the technical press, have dealt chiefly with the technical aspects of the problem. Very little has been said to show how the conclusions theoretically and experimentally established can be practically and successfully employed for the solution of problems in the field. It is the purpose of this paper to review some of the important aspects of inductive interference and to indicate by means of concrete examples, the solution of some of the practical problems met in the field. It will be our endeavor to show the sim-

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plicity of remedial measures in general in an effort to correct the idea prevalent among those who have not had time to carefully study the problem, that the measures developed to date are impracticable and burdensome.

Before proceeding to the discussion of remedial measures and their application, we believe it well to again review briefly, the factors involved, through which inductive interference arises. An understanding of these factors, and their relative importance, is necessary in order to appreciate the significance of the remedial measures.

In what follows, three-phase three-wire power circuits and metallic telephone circuits, physical or phantom, are assumed. We are concerned with voltages induced in the telephone circuit through two phenomena—electric and magnetic induction. Both effects are always present, and they combine to produce the resultant disturbance noted.

The voltage induced in the telephone circuit electrically and magnetically can be classified as:

1. Between the two sides of the circuit (referred to throughout this paper as the transverse effect).

2. Between the two sides of the circuit and ground, or along the circuit (referred to throughout this paper as the longitudinal effect).

The transverse induced voltages regulating through line impedances cause currents in the terminal apparatus. The longitudinal induced voltages, in addition to raising the telephone circuit to a potential with respect to earth which may be dangerous, cause currents in the telephone circuit owing to the differences in series impedances and admittances to ground of the two sides of the circuit.

A perfectly balanced power or telephone circuit may be defined as one in which the series impedances of the several phases and the admittances between the several phases and ground are exactly the same at every point.

If it were possible to construct a perfectly balanced telephone circuit, there could be theoretically no transverse induced voltage, regardless of the magnitude of longitudinal induced voltage provided that a sufficiently large number of exactly spaced transpositions were placed in it so as to equalize the induced voltages in each side.

Conversely, if it were possible to construct a perfectly balanced power circuit, there could be theoretically no voltages induced

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on a parallel telephone circuit, provided that a sufficiently large number of exactly spaced transpositions were placed in it so as to expose each phase of the power line equally to the telephone line.

In practise, the balance of neither power nor telephone circuits can be made perfect as defined above, and it is, therefore, necessary, in order to avoid induction into paralleled telephone circuits, to balance both power and telephone circuits as well as practicable, and also transpose both circuits with due regard to one another.

It is convenient to consider the voltages and currents in the power circuits, which cause induction, as consisting of two components:

1. Balanced voltages and currents.
2. Residual voltages and currents.

The balanced components are three voltages or currents equal in magnitude, displaced 120 degrees in time-phase with respect to one another, and whose vector sum is, therefore, zero.

Single-phase loads connected between wires cause voltage and current components whose effects are very similar to those of balanced three-phase voltages and currents, and are treated in a like manner.

The residual components are three voltages or currents equal in magnitude, in common time-phase, and whose vector sum is, therefore, not zero.*

The balanced voltages and currents are those which perform the useful functions of the power system. On the other hand, it is significant and fortunate that the residual voltages and currents are not essential to the operation of the power system.

Balanced voltages and currents are common to either of the two general types of power systems (grounded or isolated), and the remedial measures for the mitigation of inductive effects arising therefrom are identical. This is not true of the residual voltages and currents. These arise from different sources in the two types of power systems, and generally exhibit characteristics peculiar to the particular type of system.

The remedial measures for their mitigation are also distinctly different.

Thus, it will be seen that there are two different phases of the general problem of inductive interference, *i.e.*,

*See Appendix II, Report of Joint Committee on Inductive Interference. A. I. E. E. TRANSACTIONS, Volume XXXIII, p. 1461, ff.

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1. The mitigation of induction arising from the balanced voltages and currents, requiring remedial measures which are the same whether the power system be isolated or grounded.

2. The mitigation of residual voltages and currents requiring remedial measures peculiar to the particular type of power system involved.

Residual voltages and currents may arise in different types of power systems from one or more sources which act singly or together.

On grounded systems, the principal sources of residual voltages and currents are:

1. Unbalanced loads between the three-phase and neutral, causing unbalanced-load currents to flow through the neutral to earth.

2. The third harmonic and its odd multiples, due to a variation of permeability of the iron, occur in common time-phase in the three phases of the transformer banks, thus giving rise to a residual component of voltage and current in the connected transmission lines.

On systems isolated from ground, the principal source of residual voltages and currents is:

Unbalanced capacitance and conductance between the several phases and ground. The conductance factor is generally of minor importance on well constructed and maintained systems.

The tendency in the best power systems design and operation is inherently toward practises which reduce the possibility of large residuals. Moreover, the majority of the future parallels with communication circuits will undoubtedly be short, owing to the increasing tendency of both power and telephone companies to seek private rights-of-way. Were this not so, the problem of mitigation of residuals would be as difficult to combat in the future as it is at present. With the increased attention being devoted to this matter we expect that the longitudinal effects of residual voltages and currents will, in the shorter parallels, be reduced to magnitudes small enough to be relatively unimportant.

It must be realized that the inductive effect per volt or ampere of residual voltage or current is proportionately far greater than for equal amounts of balanced voltage or current. It should be clearly understood that the mitigation of residuals where parallels of considerable length are involved is of great importance. The longitudinal effect then becomes of importance by main-

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taining the telephone circuit as a whole above ground potential and producing a transverse effect by virtue of the unbalances inherent to commercial circuits.

The wave-forms have much to do with the severity of induction. Higher harmonics are present in both voltages and currents and their power of producing disturbances increases with very great rapidity up to about 800 cycles. Practically all noise in telephone circuits caused by induction from power circuits arises from the higher harmonic voltages and currents. Were these entirely absent, the problem of inductive interference would be indeed simple of solution, for then we should have to deal with only the fundamental frequency which is scarcely audible to the human ear.

The frequency and magnitude of these attendant harmonics should determine the extent of remedial measures to be applied owing to the variation in effectiveness of given remedial measures and severity of induction with the frequency.

Another important phase of the problem is the question of abnormal conditions, accidental or otherwise, on the power system. An abnormal condition in any type of power system, whether it be due to an accidental ground, short circuit, open-circuit or switching operation, produces a great increase in the residual voltage or current, or both, of the system momentarily, or for a considerable period of time, as the case may be.

On a star-connected grounded-neutral system, an abnormal condition generally produces a large residual current which is approximately equal to the short-circuit current to ground (if the condition be one of a grounded phase) on that portion of the circuit between the sources of power supply the fault and the point where the fault occurs, or if the fault be an open one in phase, the residual current will equal the unbalanced-load currents flowing in the other two phases. A residual voltage is created in proximity to the fault and in certain instances throughout the length of the circuit from the fault to the receiving transformers, which voltage approaches as a maximum 58 per cent of the voltage between phases.

On an isolated system, a ground on one phase causes a large residual voltage throughout the entire length of the circuit whose magnitude is 173 per cent of the voltage between phases. A residual current is created in proximity to the fault, its magnitude depending upon the extent, voltage and frequency of the system.

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Fortunately, abnormal conditions are becoming less frequent, owing to the demand for greater continuity of service, leading to better construction of power lines and to the use of better apparatus. There have been no remedial measures developed which can adequately care for the inductive disturbances attendant to abnormal conditions of power lines, nor are such expected.

It is, therefore, a question of reducing to a minimum the accidents on the power lines by proper construction and maintenance and of using methods and apparatus in switching which shall incur the least possible disturbances.

The difficulties encountered in attempting to mitigate the disturbances under abnormal power circuit conditions constitute an additional reason why it is very desirable to avoid parallelism wherever possible.

As an instance in which the use of improved methods and apparatus have resulted in a material reduction of transient disturbances, the charging of electrolytic lightning arresters can be cited. Since the adoption of the four-tank electrolytic lightning arrester, the use of charging resistances, and metallic contact during charging, the formerly serious transient disturbances experienced on parallel telephone lines at times of charging, have been largely reduced.

The configuration and spacing of the power-circuit conductors has an important bearing on:

1. The liability to short-circuits on the line.
2. The residual voltage (of an isolated system).
3. The resultant induction from balanced components.

Since the last two items can be cared for by transposition, the first is of chief importance.

Vertical configuration of a power circuit renders it liable to short-circuits where snow and sleet are encountered.

The equilateral triangle is far superior to either vertical or flat construction with respect to residual voltage caused by capacitance unbalance. The wishbone configuration is intermediate. For induction from balanced components, the differences are less marked, the flat configuration causing the most induction.

The configuration of telephone circuits is standardized to a far greater degree, and since transposition is comparatively inexpensive and effective, the configuration of telephone circuits is relatively unimportant with regard to the mitigation of induction.

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For the mitigation of inductive effects produced by the balanced voltages and currents, transpositions offer the most feasible, simple and effective means developed to date. A transposition in a circuit interchanges the positions occupied by its conductors. In a three-phase power circuit, a transposition changes the phase of the induction produced by the balanced voltages and currents by 120 degrees. Thus, by locating power-circuit transpositions so that each conductor occupies all of the several conductor positions for equal distances, a "barrel" is obtained within which the vector sum of the induced voltages on an untransposed parallel circuit is zero. The effect of transposing a power circuit may, therefore, be said to be one of neutralization.

A transposition in a telephone circuit changes the phase of the induced transverse voltage by 180 degrees, that is, it reverses in successive lengths the phase of the induction between the two sides of the circuit. Transposition of a telephone circuit, therefore, exposes each side of the circuit equally to the influence of the power circuit, and the effect may be said to be one of equalization. It should be noted that the phase of the longitudinally induced voltage is in no wise changed by transpositions in the telephone circuit.

This change of phase of the induction into a telephone circuit by transposition in either the power or telephone circuit, or both, affords a means of reducing inductive effects in that the induction in one section may be largely neutralized by the induction in neighboring sections.

A proper adjustment of neutralization and equalization effects by transpositions in both power and telephone circuits constitutes a "co-ordinated transposition scheme" as referred to throughout the remainder of this paper.

In Fig. 1 is shown a co-ordinated transposition scheme in the case of a three-phase power circuit and a simple metallic telephone circuit. Let the three configurations of the power circuit be designated A, B, C. Let a and a' denote the length of telephone circuit, exposed to configuration A; b, b' and c, c' are similarly defined. Primes denote that there is an odd number of telephone transpositions between the given length and the reference section of the telephone conductor. For balance to induction the lengths a, a', b, b', c, c' must fulfill the relation

$$\Sigma a = \Sigma a' = \Sigma b = \Sigma b' = \Sigma c = \Sigma c'$$

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Longitudinal induction balance for balanced voltages and currents is obtained when the condition

$$\Sigma (a + a') = \Sigma (b + b') = \Sigma (c + c')$$

is fulfilled.

Transverse induction balance for balanced voltages and currents is obtained when the condition

$$\Sigma (a - a') = \Sigma (b - b' =) \Sigma (c - c')$$

is fulfilled.

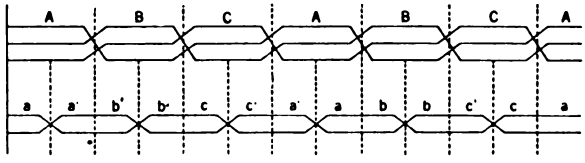

FIG. 1.

The system of "barreling" shown in Fig. 1 is called "continuous barrelling." In practise where long uniform parallels occur, it is possible and many times desirable to modify the co-ordinated system shown in Fig. 1 by omitting every third power transposition as depicted in Fig. 2, thus obtaining a system of "non-continuous barrelling."

The same conditions for balance hold for this system as given for continuous barrelling shown in Fig. 1. The only advantage

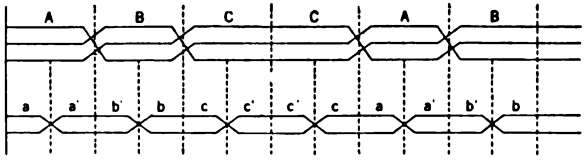

FIG. 2.

of continuous barrelling over non-continuous is that balance is obtained in any three consecutive sections regardless of the point of starting.

Power circuit transpositions with reversed rotation are sometimes used when it is necessary to obtain an exposure of a particular phase in a particular section to balance with another type exposure in some other section of the parallel. A simple illustration is shown in Fig. 3.

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It is interesting to note that the use of reversed power transpositions in the manner shown also results in not altering the relation of power wires at ends of the parallel. Reversing the rotation of a power circuit transposition changes the phase of the induction in the section of parallel immediately beyond the transposition by 240 degrees. Since a telephone transposition changes the phase of the induced voltage by 180 degrees, it is obviously immaterial whether the rotation of telephone transpositions be normal or reversed. Normal rotation is considered as that of the existing transpositions in a given power line.

Transpositions of the power circuit in no way changes the phase or magnitude of induction produced in telephone circuits by residual voltages and currents, except in so far as it changes the residual voltages and currents themselves, which happens in some cases.

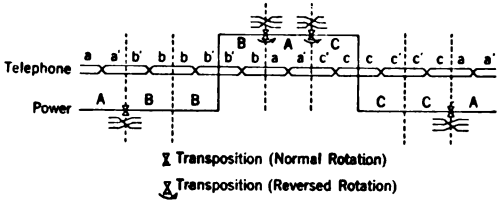

FIG. 3

Longitudinal induction from the residual voltages and currents cannot be reduced by either power or telephone transpositions. It follows, therefore, that the reduction or elimination of longitudinal induction from residual voltages and currents must come about through a reduction or elimination of the residuals themselves in the power system.

Transpositions of the telephone circuit is an effective means for reducing the transverse induced voltage produced by residual voltages and currents.

Transverse balance for induction from residual voltages and currents is obtained when the condition (see Figs. 1, 2, or 3).

$$\Sigma (a + b + c) = \Sigma(a' + b' + c')$$

is fulfilled.

When the conditions for balance cited above are not fulfilled the unbalanced exposures are as follows:

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TABLE I.

Type of Induction	Component of power circuit voltage or current	Length of unbalanced exposure
Transverse	Balanced	$\Sigma(a-a')\underline{/0^\circ} + \Sigma(b-b')\underline{/120^\circ} + \Sigma(c-c')\underline{/240^\circ}$
"	Residual	$\Sigma(a+b+c) - \Sigma(a'+b'+c')$
Longitudinal	Balanced	$\Sigma(a+a')\underline{/0^\circ} + \Sigma(b+b')\underline{/120^\circ} + \Sigma(c+c')\underline{/240^\circ}$
"	Residual*	$\Sigma(a+b+c+a'+b'+c')$

*Independent of all transpositions.

The "unbalanced exposure" is the length of exposure between untransposed telephone and power circuits which will produce inductive effects of the same magnitude as those produced in the actual exposure of the same configuration with the given transpositions in telephone and power circuits.

The unbalanced exposures of different circuits in any given parallel are of value to indicate the relative severity of the induction in the different circuits, and those corresponding to different transposition systems for a given parallel are indicative of the relative effectiveness of such transposition systems.

Summing up from the discussion above; the various factors involved and the conditions for induction balance between power and telephone circuits may be simply tabulated as follows:

TABLE II.

Type of induction	Component of power circuit voltage or current	Condition for balance	Balance depends on transpositions in
Transverse	Balanced	$\Sigma(a-a') = \Sigma(b-b') = \Sigma(c-c')$	Both lines
"	Residual	$\Sigma(a+b+c) = \Sigma(a'+b'+c')$	Telephone line
Longitudinal	Balanced	$\Sigma(a+a') = \Sigma(b+b') = \Sigma(c+c')$	Power line
"	Residual	—	—

The application of telephone transpositions in a manner to obtain the conditions for balance indicated in Table II is subject

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in practise to the condition that on telephone leads carrying more than one circuit, it is necessary to provide against induction from one telephone circuit into another, commonly referred to as "crosstalk". This necessitates a complicated telephone transposition system to provide balance for induction from outside sources such as power lines and also among all the circuits on the telephone lead.

Even though it were possible in practise to fulfill exactly the conditions for balance as indicated in Table II, there would still be present some inductive effect because of the changes in phase and magnitude of the voltages and currents along the power line. This point has an important bearing on the length of power-circuit barrel, for it is necessary in order that this effect be rendered sufficiently small, that the conditions for balance outlined in Table II be fulfilled within as short a length of exposure as is practicable. In practise, it has been found, in some cases, that barrels in the power circuit six miles in length are satisfactory. Except under very severe exposure conditions we believe that barrels in the power circuit three miles in length will afford a satisfactory solution when uniform sections of parallel are long enough to permit their use.

Points of discontinuity within a parallel, such as changes in configuration of either power or telephone circuit, large changes in the separation of the two lines, crossovers, branch loads, loading points in the telephone line, or in fact any points at which an abrupt change in magnitude or phase of the power line voltages or currents or induced voltages occurs, should in general be made neutral points. In other words, balance to induction should be obtained between such points of discontinuity independently of the remainder of the parallel. Thus the number of and distance between points of discontinuity is a controlling factor in determining the length of power-circuit barrel. It should be noted in this connection that a loading coil in the telephone circuit is a discontinuity with respect to the transverse induced voltage, but not with respect to the longitudinal induced voltage, since the loading coils are non-inductively connected in the circuit formed by the telephone wires and ground.

Crossovers of power and telephone lines within the parallel are in general considered as points of discontinuity. In some cases, however, where the same separation obtains between the power and telephone lines before and after crossover, it is possible by interchange of the pin positions of the power wires to

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make the crossover equivalent to a transposition in the telephone circuit, or in both the power and telephone circuits. If the crossover is treated in such a manner, it need not be considered as a point of discontinuity.

In Fig. 4 are shown several types of crossover transpositions represented by the terms "0° crossover", "120° crossover" and "240° crossover" which number of degrees has reference to the change in phase of the longitudinal induced voltage between the two sections immediately adjacent to the crossover.

It has been previously pointed out that transposition of the telephone circuit is an effective remedy for reducing the transverse induction from residual voltages and currents; that longitudinal induction from the same source cannot be cared for by either power or telephone transpositions, hence must be reduced by a reduction of the residual voltages and currents within the power system.

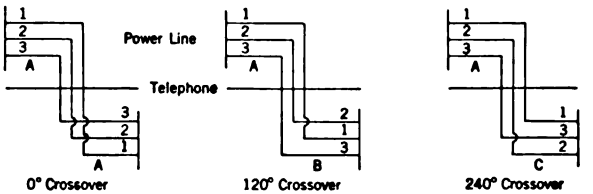

FIG. 4.

In the type of power system isolated from ground, the problem of reducing residual voltages and currents is a comparatively simple one. Earlier herein it was stated that the principal source of residual voltage and current in systems isolated from ground is the unbalanced capacitance between the several wires of the circuit and ground. Hence the remedial measure obviously necessary is a balancing of these capacitances to ground. This is most readily accomplished by transposing the power line throughout its extent (including all the lines metallically connected to the one in the parallel) so that each conductor occupies the several pin-positions for equal distances.

To a company operating an isolated system of large extent, this remedy appears to be a severe and costly measure, unless very few and widely separated transpositions will accomplish the desired result. In general, practise indicates that transpositions for this purpose can be relatively and widely separated. Here again in determining the length of barrel required, the wave-

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shape of the residual voltage is a dominant factor, since with the higher frequencies shorter barrels are necessary.

It does not seem probable that barrels of less than 6 miles in length will generally be required and in some cases longer barrels will be sufficient. Branch lines, switching points and changes of configuration must be taken into account and frequently fix the length of barrel.

In the construction of new lines, it is a very simple and inexpensive matter to cut in transpositions at reasonable distances to accomplish the reduction of residual voltage without detriment to the operation of the system. Then if parallelism occurs in the future, the only transpositions required would be in and near the parallel.

With existing parallels, it may or may not be necessary to transpose the power line outside the parallel, depending upon the severity of the exposure. In any event, all of the measures should be applied within the parallel and found insufficient before giving consideration to this point.

In the type of power system operated with a star connection of transformers and grounded neutral, the reduction of residual voltages and currents is not so readily accomplished as in the case of systems isolated from ground. Two principal sources of residual voltages and currents for this type of system have been previously mentioned herein; namely, unbalanced loads between the three-phases and neutral, and the introduction of the third harmonic and its odd multiples as residuals.

The obvious measure against the former is the removal of all grounded neutrals but one, thus removing the ground path for the unbalanced currents. In some cases this may not always be considered safe or feasible, particularly if the network be of large extent. There seems to be, however, a growing tendency on the part of power companies operating systems of large extent toward the elimination of the ground connection at all but important generating and switching points. Since the use of grounded single-phase loads has almost disappeared from practise with the larger power companies, it is now generally true that power circuits operated by such companies can be very well balanced as to magnitude of load current in the three phases and the unbalanced load current can usually be practically eliminated.

The introduction of the triple harmonics as residual voltages and currents is the chief problem of the grounded neutral system. Since these triple-harmonic voltages and currents are introduced

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through the effect of variable permeability of iron in transformers and as their magnitude is directly dependent upon the magnetic density at which the transformer is operated, this type of residual is reduced by operating the transformers below their rated voltage. There is no doubt that the practise of operating transformers over rated voltage is the cause for the large residual current of triple frequencies observed on star-connected systems, since the magnitude of these harmonics increases very rapidly as the transformer iron approaches magnetic saturation.

The employment of the delta-star connection of transformers on grounded systems is greatly preferable to the star-star connection, in that the delta winding provides a low impedance path for the triple harmonics, in parallel with the path provided by the line and earth, hence reduces the magnitude of such currents over the line and earth path.

It is difficult to accurately predict on systems employing the star-delta type of connections whether or not the magnitude of triple harmonic residual will be large enough to cause severe inductive effects, since it depends upon a multitude of considerations dealing with the interaction of different portions of the system on one another.

In the case where both star-star and star-delta banks are used, the line sides being in star with grounded neutral, the star-delta bank offers a low-impedance path for the triple-harmonic magnetizing currents of the star-star bank. Hence in the line, between two such different banks, there will be a large residual current, and an exposure occurring there is liable to serious induction. Such a star-delta bank may, however, be used as a shunt path for the triple-harmonic residuals, and greatly reduce their magnitude in the line beyond. Thus, a remedial measure is suggested for the mitigation of triple-harmonic residuals on systems employing the star-star connection.

The triple-harmonic circulating current of the delta winding is greatly increased where such connection is used in combination with star-star banks and hence a star-delta bank of size comparable with the star-star bank is required to give effective results.

On a system employing only the star-star connection of transformers with grounded neutrals, it is always a safe prediction that serious triple-harmonic residuals will be present, and it is essential that measures for their reduction be considered. Tertiary delta windings on such transformers are beneficial and new

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transformers for proposed installations of this connection should be designed to provide such windings. Power engineers recognize the advisability of providing such windings for their own benefit when using this type of connection so that much of the trouble formerly experienced will thereby be eliminated in the future.

The interconnected-star is a method of reducing triple-harmonic residuals by neutralization. Besides being less efficient than the star-delta connection, it reduces the voltage rating by 13 per cent and requires a more complicated arrangement of the wiring.

It will be seen from the above discussion of the mitigation of residual voltages and currents under normal operating conditions, that:

1. In isolated delta-connected systems, residuals may be effectively and easily reduced by simple means.

2. In star-connected grounded systems, several measures can be practised for reducing residuals all of which will reduce them with some degree of success but none of which are entirely satisfactory.

Types of power-circuit transpositions and barreling have been described previously and their application to the practical case will be readily understood. In the case of telephone transpositions, only a single metallic circuit has been considered in the discussion of the co-ordination of transpositions, without reference to cases where more than one telephone circuit is involved other than to mention the fact that the problem was further complicated.

For the application of co-ordinated systems of power and telephone transpositions to the practical case, a telephone transposition system has been designed which will care for as many as forty telephone wires (20 physical and 10 phantom circuits), providing adequate crosstalk balance between the telephone circuits themselves and being capable of properly co-ordinating with power-circuit barrels of varying lengths. Further work is in progress which will extend this system to a full eighty-wire lead.

This system is known as the "exposed line system". It is comprised of two types of sections as follows:

1. Exposed line *A* section.

2. Exposed line *X* section.

Additional short sections, whose characteristics have not, as

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yet, been determined, are in the process of development; namely, the exposed line *Y* and *Z* sections.

The exposed line *A* section is nominally eight miles in length with 32 transposition points for the circuit most commonly used, and has been designed to give high crosstalk-balance together with induction balance to power lines transposed:

1. Opposite any mile-points of the telephone transposition system.

2. With two complete barrels (five transpositions of the power line) between mile-points of the telephone transposition system.

Thus, for a uniform parallel, this section gives balance to induction from power lines transposed with six-mile, three-mile or one-half mile barrels. It is possible to adjust the length of this nominal eight-mile section to any value less than eight miles, and this is frequently done in adjusting the sections or mile-points to correspond with discontinuities in the parallel. Transverse balance of all circuits to induction is accomplished in every mile.

The exposed line *X* section is nominally one-half mile in length with four transposition points, and is so designed that any number of units may be installed end to end. The *X* section unit does not balance to power lines transposed within any one unit, but is designed to be so used that transpositions of the power line and discontinuties of the exposure occur at junction points between successive units. Thus balance to induction is obtained in three successive sections if power transpositions are located opposite their junction points. Nominally this would give a power circuit barrel of one and one-half miles. The *X* section can be made of any length less than one-half mile per unit where required.

Short exposed line sections may be used in any part of an eight-mile loading section, and the remainder transposed according to some other transposition system.

By "other transposition systems," reference is made to the "standard system" which involves the use of four sections, *A*, *X*, *Y*, and *Z*, whose nominal lengths are 8, ½, 1½ and 4 miles respectively. In the standard system, however, balance to induction from outside sources, such as power lines, is not obtainable except by modification of certain of the transpositions involved. Also, the use of the *X*, *Y*, or *Z* sections consecutively is not permissible without modification.

Another method sometimes used is to superimpose on the

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cross talk transposition systems, already in the line, special transpositions of all the telephone circuits on poles between the regular transpositions poles. That is, their function is to transpose all circuits with reference to outside circuits so as to give a minimum of disturbance to the crosstalk balance of the telephone circuits themselves. The prime purpose of "whole-line" transposition is, therefore, to make possible the retention of systems of transposition involved in parallelism which do not provide balance to induction in themselves. The use of whole-line transpositions is limited by crosstalk considerations to some extent where phantom or loaded circuits are involved. Their chief application is to very short parallelisms.

There are two types of whole-line transpositions; namely, the quarter-mile unit and half-mile unit. These are shown in Fig. 5.

The use of short sections or whole-line transpositions is dele-

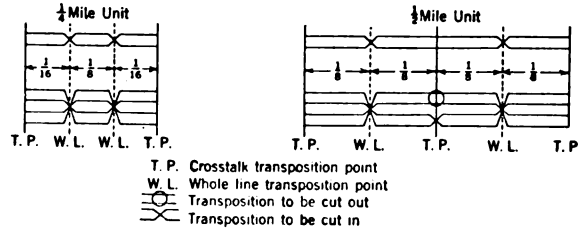

FIG. 5.

terious to the telephone service in that it is impossible with these arrangements of transpositions to reduce cross-talk as effectively as with eight-mile sections. Moreover, the difficulty of maintenance of telephone service is increased.

In order to illustrate in a more comprehensive manner the application of remedial measures, such as have been described and discussed in the previous sections of this paper, a few concrete examples will be cited and their solutions discussed. Before doing this, however, we believe it well to call attention to the fact that the successful design of remedial measures necessitates an exact knowledge, on the part of the engineer, of many details of the particular case. Not only must he be thoroughly conversant with the telephone circuits involved, but he must also be conversant with the characteristics of the power system involved. It is highly desirable that a personal inspection be made and copious notes taken in order that all

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practical difficulties be observed in advance of the design of remedial measures. That it is not possible for the engineer to personally inspect every case is recognized, hence the data must ofttimes be collected by some other person, and it is, therefore, necessary that a procedure be devised for presenting an accurate and detailed report to the engineer for his guidance.

Through the courtesy of The Pacific Telephone and Telegraph Company, we present in Appendix I of this paper the pertinent part of an engineering circular, describing a procedure for surveying a case of parallelism and for transmitting an accurate account of the essential facts, which we have found exceedingly satisfactory.

In the examples which follow, the symbolic representations described in Appendix I are used, and the reader is referred to this Appendix for their explanation.

The foregoing text has emphasized the fact that the severity of requirements of transpositions and balance which muct be imposed on the circuits in a parallel depends largely on the wave shape of the generating apparatus as well as on the fundamental frequency of the power system and on other local conditions. This fact has been taken into account in the examples given below. In cases II and III the number of transpositions in the power circuits is less than would in many cases give satisfactory results, but in case II represents an arrangement which was applied with success, and in case III, one which it seems reasonable to install, in a particular case which has arisen.

Case I

Case I presents an example of a uniform parallel involving three power circuits (see illustration) whose parallelism is coincident for a little over half of the total parallel. The case was presented for solution as a practical problem in the field, and the remedial measures are to be described have been installed in part and found effective. The details of the parallel and characteristics of the power lines and telephone system are as follows:

Power Systems No. 1. 30,000 volts, three-phase, 50 cycles, vertical configuration; tower construction; star-star connected and star-delta connected transformer banks employing a ground connection. No transpositions.

No. 2. 15,000 volts, three-phase, 50 cycles. Flat configuration; pole construction; star-star connected transformer bank

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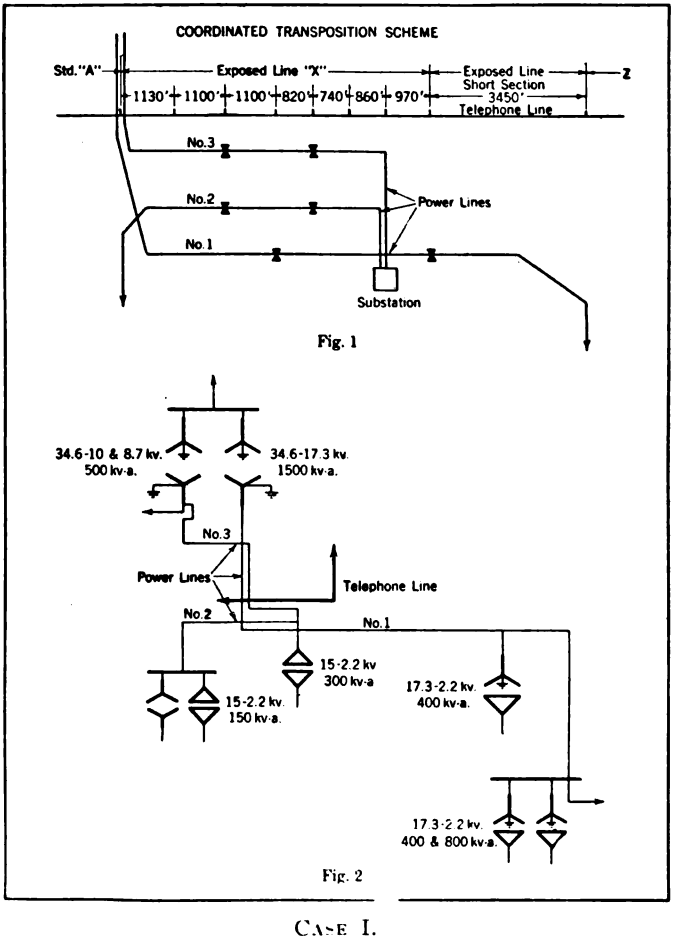
supply with grounded neutral and delta-delta and star-star (isolated neutrals) connected load banks. No transpositions.

No. 3. 15,000 volts, three-phase, 50 cycles. Triangular configuration; pole construction; star-star connected trans-



CASE I.

former bank supply with grounded neutral and delta-delta connected load banks. No transpositions.

Telephone System. High-grade loaded physical and phantom long distance circuits; ultimate capacity of lead 40 physical and 20 phantom circuits. Standard system of transpositions.

Parallel. 10,170 feet in length; separation of power and

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telephone leads: No. 1, 75 feet; No. 2, 49 feet; No. 3, 18 feet. Crossover at beginning of parallel circuits No. 1 and No. 3.

Co-ordinated Transposition Scheme. The variation in length of parallelism of the three power lines, different separations from the telephone line, difference in voltages, configuration and transformer connections as indicated above and on Case I, coupled with the added fact that the parallel is short and located in the middle of a telephone loading section which could not be disturbed as to length, makes this case a very interesting example of transposition-coordination and residual-mitigation.

Short transposition sections of the exposed-line type offer the most feasible solution and the coordination was accomplished as follows.

Considering power circuit No. 1, one barrel within the exposure was deemed sufficient to accomplish satisfactory longitudinal balance to the balanced voltages and currents. Hence the section of power line involved within the parallel is divided into three equal sections by the installation of transpositions therein at the towers adjacent to the one-third and two-thirds points.

Circuits No. 2 and No. 3 are operated in parallel and their exposures to the telephone line are coincident, hence accomplishing longitudinal balance by means of one barrel in each circuit within their exposure is feasible. Therefore, the length of parallel involving these circuits is divided into three equal sections by transpositions installed in the two power circuits at the one-third and two-thirds points.

Transverse balance to induction from both the balanced and residual voltages and currents is accomplished by using exposed line X sections of such length that their junction points fall opposite the power-circuit transpositions as depicted in Fig. 1 of Case I. From a point opposite the second transposition in power circuit No. 1 to the end of the parallel, a "Y" section is used since no discontinuities intervene to require shorter sections.

Mitigation of Residuals. The mitigation of residuals for this case brings out some interesting features. Considering Circuit No. 1 (see Fig. 2, Case I), a combination of star-star and star-delta connected transformer banks, with grounded neutrals is employed. As pointed out in a previous section of this paper, a condition is here established which is conducive to the passage of large triple-harmonic residual currents over the power line past the exposure with consequent heavy longitudinal induction on the telephone circuits. The obvious measure for reducing

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such effect was to remove the low-impedance path of such currents. Accordingly, it was suggested that the neutral on the low side of the star-star connected supply bank of transformers be ungrounded. This request was acceded to and the residual current was thereby reduced to a value small enough to have no appreciable inductive effect on the telephone circuits.

With the neutral of the No. 1 circuit supply bank grounded on the low-voltage side, some transient disturbances on the 60,000-volt line feeding the bank were transformed and caused severe trouble on the telephone circuits. The ungrounding of the neutral eliminated this trouble.

Circuits No. 2 and No. 3 are supplied from a star-star connected bank employing a grounded neutral, but all other transformers on the two lines are isolated. The star-connected supply bank has two taps on the low side so that power may be supplied at star voltages of 10,000 and 8,700 volts. From the 10,000-volt tap energy is supplied over a third circuit not involved in the parallel. Hence a shunt path is provided for the third-harmonic residuals, thus reducing the magnitude of such current in the line involved in the parallel. This condition, coupled with the fact that a high-impedance path is offered to residual currents via the earth due to the presence of a ground at but one end of the circuit, sufficiently reduces the magnitude of residual current in this short parallel so that its inductive effect can be tolerated.

Case II

Case II presents an example of a parallel with a power circuit employing a grounded neutral at one point only. (See illustration, Case II). It is of interest to state at the outset that this parallel is one which has recently been studied, the remedial measures outlined below installed in part and elaborate tests made to determine their efficacy. The details of the parallel and characteristics of power and telephone systems are as follows:

Power System. 60,000 volts, three-phase, 60 cycles, triangular configuration; 6-foot spacing; delta-delta connected transformer banks throughout the system with one exception; a star-connected bank with grounded neutral at one end of the line (see Case II.) Three existing transpositions; two within parallel and one outside.

Telephone System. One long-distance telephone circuit and several long suburban circuits. Standard system of transpositions.

Parallel. 75,090 feet in length; separation between power

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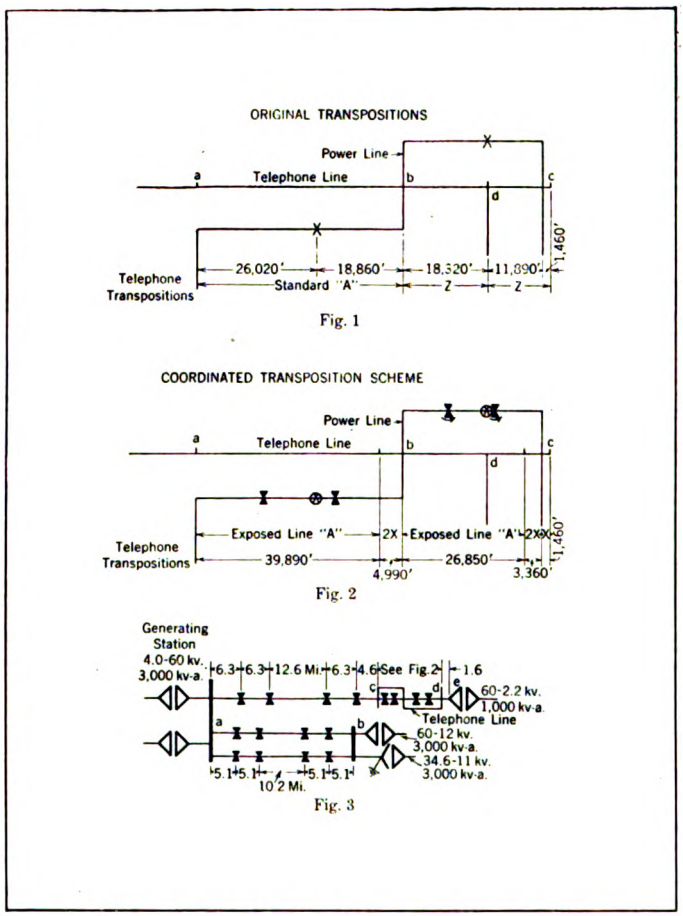
and telephone leads, 45 feet. Two crossovers, one of which is at the end of the parallel.

Co-ordinated Transposition Scheme. In this case a long uniform parallel is presented which offers an excellent opportunity for the use of the exposed line *A* section.



CASE II.

The method was adopted of installing first a very small number of transpositions in the power circuit to determine the extent to which the induction was reduced. The design is such that additional power transpositions can be economically installed if later found desirable.

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Referring to Fig. 2, Case II, beginning at point *a* (the commencement of parallelism) an exposed line *A* section is installed of such length that it occupies eight-ninths the total distance from point *a* to the crossover at point *b*. Thence, two *X* sections of equal length extend to the crossover point *b*. Transverse balance is obtained when the existing power transposition is removed. Longitudinal balance to induction from the balanced voltages and currents of the power system is accomplished by installing a barrel in the power circuit between points *a*, *b*, with two transpositions opposite the three-ninths and six-ninths points of the telephone transposition system.

From the crossover at point *b*, another exposed line *A* section is installed of such length that it occupies eight-ninths the total distance from point *b* to the end of the parallel at point *c*. Thence two *X* sections of equal lengths are installed, extending to the end of the parallel, at *c*.

Transverse balance is obtained when the existing power transposition in this section is removed. Longitudinal balance is obtained in the same manner as outlined for section *a*, *b*, but with reversed rotation of power transpositions, the purpose of which will be explained below.

Thus, coordination of the power and telephone systems is obtained within the parallel in so far as induction from balanced voltages and currents of the power system are concerned, and also transverse induction balance from the residual voltages and currents.

It will be noted by referring to Figs. 1 and 2 that a junction occurs in the telephone line at a point *d* which would ordinarily be treated as a point of discontinuity, and, therefore, balance to induction should be obtained on either side of it. In this case, such balance is unnecessary since the junction point shown represents a tap off the long distance circuit under consideration. Had one or more circuits branched from the lead or terminated at this point, the other running through, it would have been necessary to make the junction a neutral point and obtain balance independently on each side. This would probably have required the use of short sections in the telephone line and two additional transpositions in the power line.

Mitigation of Residuals. Due to the presence of the grounded-neutral bank at one station and the triangular configuration used in most of the system the effect of capacitance unbalance of the lines in causing residual voltage will be very small. Hence

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under the operating condition shown in Fig. 3 transpositions outside the parallel were not in this case necessary. The manner of locating such power transpositions for capacitance balance is however shown in Fig. 3. When the grounded-neutral bank is disconnected from the system there is a considerable residual voltage due to the vertical configuration of the two lines *a b*. The line *a e* being triangular has a much lower capacitance unbalance. Moreover the ultimate replacement of the grounded-neutral bank by a delta-delta bank is contemplated. An attendant advantage of transposing this line throughout its length is the improvement of the power-system telephone circuit which is located on the power-circuit poles.

In view of these considerations it was deemed desirable to rely upon the efficacy of the coordinated transposition system and balance of telephone circuits to avoid interference from the triple-harmonic residuals due to the grounded-star transformer bank.

The plan devised for obtaining an approximate capacitance balance is outlined below. If the transpositions according to this scheme prove to be insufficient others can economically be added.

Considering first the two power circuits *a b* (see Fig. 3 Case II) operating in parallel, two 15-mile barrels are installed in each line.

The section involving the parallel *c,d*, is already balanced by virtue of the two barrels installed to co-ordinate with the telephone transposition system and provide longitudinal induction balance within the parallel. Hence one section, *a,c*,and a second section on the other side of the parallel, *d,e*, remain unbalanced. In the section *a,c*, there is an existing transposition, to be retained if possible. Therefore, two barrels of unequal length were installed in the section *a,c*, utilizing in one of them the existing transposition; by reversal of the two transpositions within the section of parallel *b,c*, Fig. 2, the proper type of exposure occurs in the section *d,e*, Fig. 3, which, considered with the section from the existing transposition to point *c* makes up the deficiency in length of the barrel. Hence capacitance balance is obtained by the use of two 19-mile barrels, although using a detached section of power line for balance. This case again illustrates the use of the reversed rotation of power-circuit transpositions.

It may be stated in connection with this case that the transpositions for capacitance balance and reduction of residual vol-

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tage in the power system have not, as yet, been installed. The reason that they were not installed, is that under the present conditions of operation the coordinated transposition system within the parallel was determined by test to be sufficient to provide the requisite relief and that the longitudinal effect of the present existing residual currents and voltages was sufficiently small not to warrant greater refinement at this time.

CASE III

In Case III (see illustration Case III) is given a typical example of parallelism between a telephone line and a power line operated isolated from ground. The details of this case are as follows:

Power System. 22,000 volts, three-phase, 60 cycles. All three conductors in same horizontal plane, spacings 35 and 65 inches. Delta-delta transformer connections at three stations. Three existing transpositions within the parallel.

Telephone System. Long-distance telephone circuits; 10 physicals and four phantoms. Standard systems of transposition.

Parallel. 38,970 feet in length; separation between power and telephone pole leads, 50 feet. Five crossovers.

Coordinated Transposition Scheme. Owing to the number of points of discontinuity in this case (crossovers) short telephone transposition sections (X sections) in combination with an A section, all of the exposed-line type, together with power-circuit transpositions as shown in Fig. 2 of Case III, give the best arrangement.

From the first neutral point of the telephone transposition system a (end of an existing section) adjacent to the beginning of the parallel, a Y section is installed, terminating at the first crossover b (beginning of the parallel). Thence, two exposed line X sections of equal length to the second crossover c, thus obtaining transverse induction balance of all telephone circuits in the section of parallel b,c, from both the balanced and residual currents and voltages of the power system. From the second crossover c to the third crossover d, three X sections are installed two of which are of equal length inserted between the crossover and the existing transposition in the power circuit. A transposition is installed in the power circuit opposite the junction point of the first two X sections. Transverse balance and approximate longitudinal balance to induction are accomplished by this arrangement in section c,d. If the existing transposition

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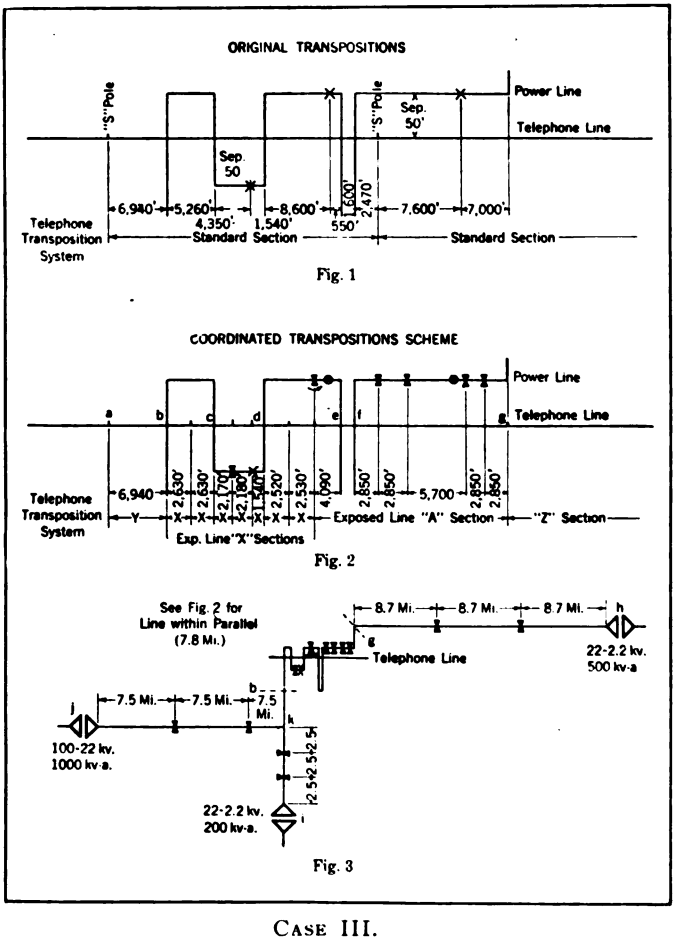
in the power circuit had been at one of the third-points of $c\,d$, exact longitudinal balance would have been obtained. It will be seen that here a sacrifice in longitudinal balance was made in order to retain an existing power transposition.

From the third crossover d to point g, the end of the parallel,



CASE III.

two X sections and one A section are installed. The exposed line A section is of such length that the pole at two-eighths of its length falls at the crossover point f. The two X sections are installed between the point d and the first pole in the A section and are of equal length. A power circuit transposition of re-

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versed rotation is installed opposite the junction of the A and X sections, thus giving in combination with the section b,c, approximate longitudinal balance in the total section b,c, and d,e. The existing power transposition in section $d\,e$, is removed. Whole-line transpositions are installed in the A section between the one-eighth and two-eighth points in order to reduce the transverse unbalance incurred due to the interruption in parallel from e,f. Thus, transverse balance has been obtained in the section of parallel d,e.

In section f, g, power transpositions are installed opposite the three-eighth, four-eighth, six-eighth and seven-eighth points of the A section, thus accomplishing longitudinal and transverse balance to induction in this section. The existing power transposition in the section f, g, is removed.

It will be seen that a coordinated system of power and telephone transpositions has been applied which balances to both transverse and longitudinal induction from the balanced voltages and currents of the power system, and transverse induction from the residuals of the power system.

Mitigation of Residuals. Since in this case an isolated system is involved and the flat configuration causes a large residual voltage, the remedial measure required is transposition of the power circuit outside the parallel in such a manner as to balance the capacitance to ground of the several phases.

In order to determine how small a number of transpositions would give relief in this case, it is proposed to install very long barrels in the sections of power line beyond the exposure, as indicated in Fig. 3. These will not be entirely effective if high-frequency components in the power circuit are prominent. The method of laying out these transpositions is as follows:

The transpositions of the power circuit within the parallel for longitudinal induction balance from the balanced voltages and currents also provide capacitance balance for this section of power line. It remains to transpose the section of line outside the parallel so that capacitance balance is obtained throughout.

In the section between one limit of the parallel g and the substation h (26 miles), one barrel is cut in the power line by installing two transpositions of normal rotation at the one-third and two-third points.

In the section between the other limit of the parallel b and substation j (22.5 miles), a barrel is cut in the power line by installing two transpositions of normal rotation at the one-third and two third points.

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The section from the power line junction point *k* to substation *i* (7.5 miles) is cared for in a like manner.

Thus, in each of the four sections cited, capacitance balance is obtained. Attention is called to the manner in which the practical consideration such as length of line and location of discontinuities arbitrarily determine the length (maximum) of power circuit barrel both from the standpoint of coordination of transpositions and measures for capacitance balance.

This case is one which was presented for solution in the field. However, for the purpose of simplifying the discussion, the extent of power system beyond either end of the parallel has been greatly reduced.

The above cases, it is thought, will serve to give a general idea of the practical methods pursued in the field for the solution of inductive interference problems. It must be remembered that the remedial measures set forth in the above cases are not necessarily applicable to other cases, and that each case requires a consideration of its particular conditions in order that adequate remedial measures may be provided.

In conclusion, we can say with conviction, based upon the facts cited in this paper and our actual experience, that the general problem of inductive interference involving three-phase circuits, while seemingly difficult of solution, is in fact, when fairly and reasonably approached, usually simple and inexpensive. The remedial measures employed, when properly designed and installed, are very effective. It is true that occasionally a problem will arise, the solution for which will impose some burden on one or both interests involved. When such a problem does arise, it is capable of solution only through a broad co-operative spirit between the two parties and their mutual willingness to bear such burden for the welfare of the community.

APPENDIX I

DATA REQUIRED IN CASES OF PARALLELISM

TO FACILITATE THE DETERMINATION OF REMEDIAL MEASURES FOR THE MITIGATION OF INDUCTIVE INTERFERENCE

The severity of the inductive interference with telephone service caused by any given parallel is dependent upon the physical characteristics of the parallel, the electrical characteristics and method of operation of the power system, and the condition of the telephone circuits. The following pages describe the data

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necessary for a study of a parallel to devise means for the prevention or reduction of inductive interference arising therefrom. In order that the best results may be secured, the instructions given herein concerning the preparation of the report transmitting the required data should be very carefully followed.

In the case of a proposed parallel, or general reconstruction of an existing parallel, a study shall be made to determine whether or not other routes are available, for either the telephone or power lines involved, which will avoid the parallel. A report on possible alternatives shall be presented in connection with the transmittal of other data concerning the parallel.

The forms and instruction of this circular have been devised to facilitate a complete report on parallels already in existence; the same general plan can be followed, however, for proposed parallels.

If any of the data are doubtful the best obtainable information shall be given and its degree of reliability stated.

A—Telephone and Power Line Data. A form for reporting the data regarding the power and telephone line is given. The form should be typed or mimeographed as convenience dictates. It is self-explanatory as to information required.

B—Exposure Chart. The telephone pole line involved in a parallel shall be plotted as a *straight line*, from left to right in the direction of transposition. The scale should be 4000 feet per inch, or 2000 feet per inch for short parallels and any case where complications render a smaller scale undesirable.

The power line *and all arc circuits, distribution circuits of* 2200 *volts or over, telephone, telegraph and signaling lines of other companies*, shall be plotted so as to indicate continuously along the telephone line the horizontal separation between the telephone pole line and the pole or tower lines supporting such other circuits. *These are to be plotted only within the exposure to the high-voltage power line.*

The scale for plotting separation will depend on the average separation; 50 feet per inch is usually convenient. The accompanying exposure chart, shows an example of a parallel and how the chart is to be plotted.

Distances measured along the telephone line from a given reference point, (and corresponding telephone pole numbers) shall be shown for:

a. each telephone transposition pole, with transposition lettering

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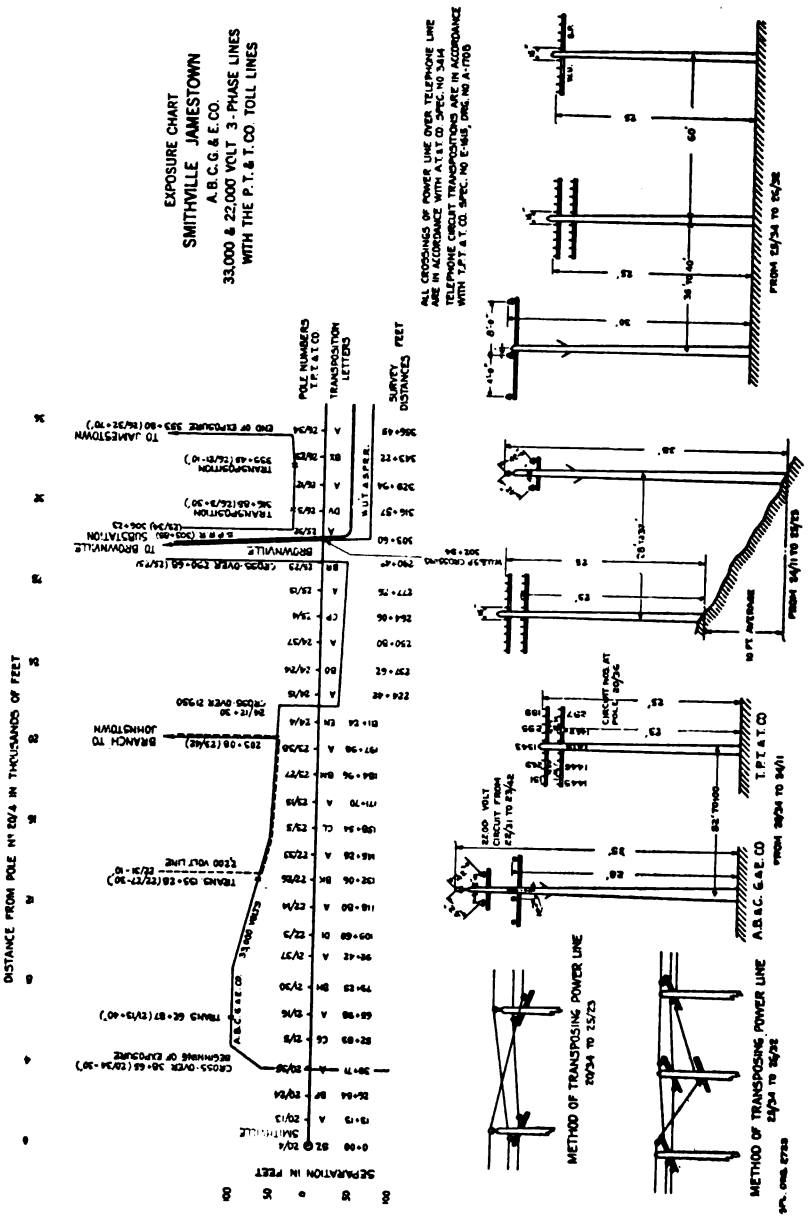
EXPOSURE CHART
SMITHVILLE JAMESTOWN
A.B.C.G.& E.CO.
33,000 & 22,000 VOLT 3-PHASE LINES
WITH THE P.T.& T.CO. TOLL LINES
DISTANCE FROM POLE Nº 20/4 IN THOUSANDS OF FEET
SEPARATION IN FEET
POLE NUMBERS T.P.T.& T.CO
TRANSPOSITION LETTERS
SURVEY FEET
SMITHVILLE
BROWNVILLE
BRANCH TO JOHNSTOWN
TRANS 65+87 (21/13+40')
TRANS 65+28 (22/27-30')
2300 VOLT LINE
A.B.C.G.& E.CO
METHOD OF TRANSPOSING POWER LINE 20/24 TO 25/23
METHOD OF TRANSPOSING POWER LINE 25/24 TO 26/26
ALL CROSSINGS OF POWER LINE OVER TELEPHONE LINE ARE IN ACCORDANCE WITH A.T.&T.CO. SPEC. NO 3414
TELEPHONE CIRCUIT TRANSPOSITIONS ARE IN ACCORDANCE WITH T.P.T.& T.CO. SPEC. NO E-1645, DWG. NO A-1700
FROM 23/34 TO 25/26
FROM 24/11 TO 25/23
FROM 20/24 TO 24/11
T.P.T.& T.CO
A.B.C.G.& E.CO

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b. loading points

c. beginnings and ends of parallels

d. points where power lines cross over telephone lines

e. points where abrupt changes in separation occur

f. points where changes in configuration of power or telephone circuits occur

g. location of bridged stations and sections of cable in the telephone line

h. power-circuit transpositions

i. points where load or feeder branches connect with power line

j. places where there are spans of excessive length; river crossings, R. R. crossings, etc.

k. each tower in case power circuit is supported on towers.

The chart shall contain as many sketches of the cross-section of the exposure as are needed to show the several types of construction, configuration and relative location of lines. A note under these shall specify the point at which each type begins and ends. These diagrams should show:

a. average pole or tower heights.

b. difference in elevation of ground under the two lines.

c. dimensions to locate points of support and spacing of all wires on poles or towers

d. traffic numbers of telephone circuits with the number of the pole to which they apply.

A sketch shall be given showing the method employed in transposing the power line and number of poles involved in a transposition.

If special construction is employed at power line crossings, the details shall be given in the report.

Any special construction in the telephone line, such as at river crossing, shall be described in the report.

The chart shall contain a title including the number of the parallel, location, companies involved, voltage of power lines, and date.

The survey of the telephone line shall determine the location of telephone transposition poles, crossovers, power-circuit transposition poles, and other features to at least the nearest 10 feet. This distance should be the "wire distance", where obtainable from the records.

Horizontal separation of pole lines shall be measured within 2½ per cent (thus, where the separation is 20 feet, it shall be

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obtained to the nearest foot, if 100 feet, to the nearest five feet). The heights of wires above the ground shall be given to the nearest foot. The horizontal and vertical distances between wires of a power circuit and wire spacing on the telephone line shall be given to the nearest inch.

Many minor irregularities must be neglected, but the purpose should be to present the average conditions as faithfully as practicable, and to give data of all pronounced changes in the character of construction.

C—Circuit Diagram of Power System. Much of the required information concerning the power circuit can be shown diagrammatically as indicated in accompanying illustration. This diagram shall show:

a. All lines or apparatus *metallically* connected to the power circuits involved. Auto-transformers constitute metallic connections between lines of different voltages, hence the circuit diagram should not terminate in such transformers. Lines or apparatus which are connected to the circuit involved in the parallel by two-coil transformers are not required to be shown.

b. Method of connection of both primary and secondary sides of all transformer banks connected to the circuits. Indicate particularly the condition of all neutrals, whether grounded or not. Where single-phase, open delta or Scott connections occur, the particular phase, to which each wire is connected shall be shown.

c. Type and location of air and oil switches.

d. Type, location and connections of lightning arresters.

e. Location and ratio of potential and current transformers; location and range of ammeters in neutral ground connections.

f. Transpositions in the power circuits.

g. The length of power circuit between all points of importance, such as stations, branch points, transposition points, and points where configuration changes, to the nearest 0.1 mile.

h. Voltages and capacities of transformers or other apparatus connected to the circuit.

i. A cross-section of the power circuit at some one point with the conductors numbered to show their respective positions. If there are two or more circuits, the wires composing each shall be designated.

The title should include name of power company, number of the parallel, location, voltage of power circuits, date and legend.

A list of symbols for use in making up power-circuit connection

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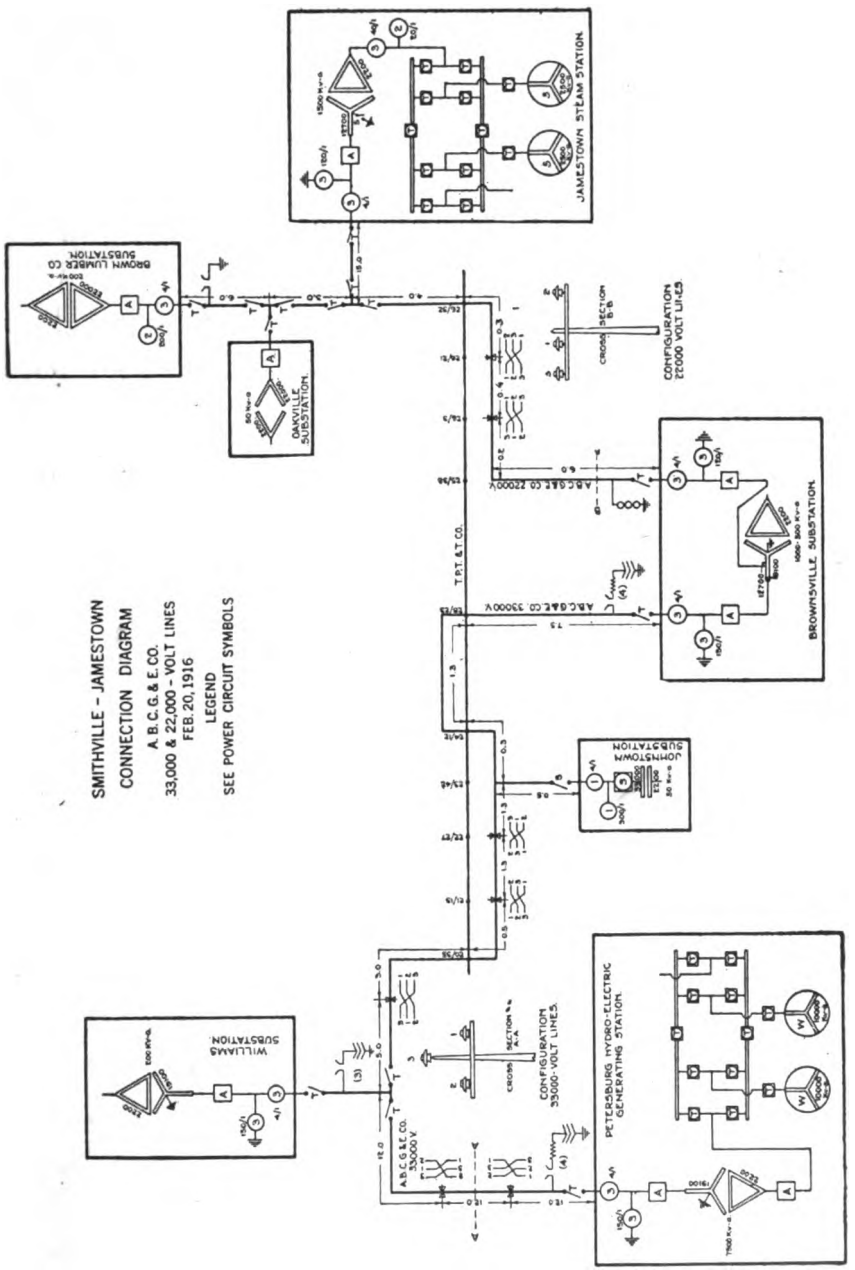

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SYMBOLS—POWER CIRCUITS—E. C. 134

Horn gap lightning arrester.

Aluminum cell lightning arrester state in parentheses the number of units.

Same as above except with charging resistances.

Multigap lightning arrester.

Air Switch S-single poles independently operated. T-three pole interconnected.

Same as above with the addition of fuses.

Oil switch-automatic all poles mechanically interconnected.

Oil switch-non-automatic all poles mechanically interconnected Use "S" in place of "T" if poles are not interconnected.

(RATIO) Current transformers place figure inside circle indicating number of units.

(RATIO) Potential transformers connected between phases. Place figure inside circle indicating number of units.

(RATIO) Same as above—connected between phases and ground.

S. or W. 7,500 kv-a. Generator—three phase delta connected 7500 kv-a S-steam driven W-water wheel driven

S. or W. 10,000 kv-a. Generator—three phase star connected, neutral grounded, (if neutral is isolated omit indication of ground) 10,000 kv-a. (S and W same as above.)

Miscellaneous apparatus write description in rectangle or reference to descriptive note.

22000 50 kv-a 2200 Transformer—single phase connection 22,000/2200 volts 50 kv-a.

Power circuit transposition.

Transformers. Unless otherwise stated on the connection diagram single phase units are assumed.

22000 2200 1,500 kv-a. Delta-delta connection 22,000/2200 volts, 1500 kv-a per unit.

22000 2200 200 kv-a. Open-delta connection 22,000/2200 volts, 200 kv-a per unit.

12700 2200 1,500 kv-a. Star-delta connection neutral grounded, ammeter in neutral 12,700/2200 volts, 150 kv-a per unit.

12700 1270 1,500 kv-a. Star-star connection neutral isolated 12,700/1270 volts, 1500 kv-a per unit.

55000 32000 1000 kv-a. Star-connected auto-transformers neutral isolated. 55,000/32,000 volts, 1000 k-va per unit.

55000 32000 2200 1000 500 kv-a. Star-connected auto transformers neutral grounded, 55,000/32,000 volts, 1000 kv-a per unit. Tertiary delta 2200 volts, 500 kv-a per unit.

11000 2200 150 kv-a. Scott-connection 2 to 3 phase 2200/11,000 volts, 150 kv-a per unit.

Note—Other transformers connections should be indicated in an analogous manner.

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diagrams, in the manner shown in the illustration is given herewith.

D. General Route-Map. The power and telephone lines shall be plotted on a map whose scale may be several miles per inch. Where available, the U. S. Geological Survey topographical maps are very convenient for this purpose. The toll route-maps of the telephone company can sometimes be advantageously used as a basis. The telephone line shall be indicated as far as the adjacent *S* poles outside of the parallel. The power circuit and substations shall be shown to an extent corresponding to the diagram of connections. In case the extent of the power system makes this impractical, a separate geographical map of the system shall, if possible, be obtained from the power company. Possible routes for either line to avoid the parallel shall also be indicated on this map.

DATA CONCERNING TELEPHONE AND POWER LINES INVOLVED IN A PARALLEL

.....Division Paralled No.....

.....191.....

I. General

1. Location of parallel.....
   (Between what towns?) (State)
2. Length, along telephone line.....miles.
   (distance between limits)
3. Name of power company.....
4. Number of power circuits.....
5. Is the parallel existent or proposed?.....
6. Which is the senior company?.....

II. Telephone Line

1. If parallel is existent, state in detail the nature of the observed trouble.....
   .....
2. What other parallels are there involving these telephone lines?
   .....
3. Is there trouble from secondary induction?.....
4. State the present physical condition of the telephone line. How soon will it require general reconstruction? .....
   .....
5. Insulation of telephone circuits
   Relative noise on telephone circuits

Circuit No.	Insulation-Megohms per mile			Relative* Noise %
	Tip	Ring	Mutual	
.....	.....	.....	.....	.....

*Estimate noise in per cent of noise on noisest circuit rated at 100 per cent.

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6. What is the ultimate capacity of the telephone line?

.....

7. State specification and drawing numbers of telephone transposition system.....

.....

8. If any circuits are loaded, state the location of loading points, give pole numbers within the parallel and at the adjacent loading points outside of the exposure, and state whether or not loading point is an **H** fixture.....

.....

9. What types of insulators are used on the telephone line?.....

.....

What types of insulators are used at loading points?.....

.....

10. If the apparatus connected to any circuit is not standard T. P. T. & T. Co. equipment, describe it.....

.....

11. State location of any points within the parallel at which circuits enter cable (*e.g.*, river-crossings). Give specification number of cable.....

.....

12. Do any circuits branch from the telephone line within the exposure? If so, state traffic numbers and points of branching. If local circuits are also involved in the parallel, give their points of branching.....

.....

13. Telephone Circuits involved in the Parallel

Traffic No.	Physical or phantom	Size & material of wire	Loaded or non-loaded	Terminals
.....	.....	.....	.....	.....

14. Describe special construction in telephone line at river crossings, etc.....

.....

15. State any other pertinent information.....

.....

III. Power Circuit No.....*)

1. Voltage.....
(actual operating voltage between wires)
2. Number of phases....., Frequency.....cycles per sec.
3. Power circuit supplied from.....Station.....
4. Power circuit supplies energy to.....

.....

5. Character of load, motor, lighting or both.....

.....

6. Average current per phase.....amperes.
7. Average daily maximum current.....amperes.

*If there are two or more power circuits they should be reported separately and every sheet marked to indicate (by number) the particular circuit reported thereon.

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8. Hour at which peak load occurs.....
9. If the neutral points are grounded, are there ammeters in the neutral connections?.....
10. State their range.....
11. Are they connected directly or through current transformers?
.....
12. Give ratio of transformation.....
.....
What is the average neutral current?.....amperes.
13. Size of conductors.....ga.
Material of conductors.....
14. In case the power line is existent state its present physical condition. How soon will it require general reconstruction?
.....
15. Type of insulators.....
Are the insulator pins grounded?.....
If suspension insulators, state number of discs.....
16. Lightning arresters.

Location	Type	Connections	Frequency and time of day of charging	Charging current-amperes per phase

What is the method of charging?.....
.....

17. Switches

Location	Type	Mechanically interconnected for simultaneous action?	What devices are there for automatic operation of switches?

18. Transformers

Location	No. of units	Mfr.	Kv-a. rating	Voltage rating	Form No. etc.	Single or three-phase	If three-phase, shell or core type

19. Rotating apparatus. If generators, motors or converters, etc., are metallically connected to a circuit involved in a parallel or if such circuit connects directly to a generating station, give data as to

Kind of Apparatus	Location	No. of units	Mfr. Type	Kv-a. rating	Voltage rating	Electrical connection

20. State other pertinent information.....
.....

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To be presented at the 33d Annual Convention of the American Institute of Electrical Engineers, Cleveland, O., June 27-30, 1916.

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(*Subject to final revision for the Transactions*)

STANDARDIZATION

BY C. LE MAISTRE

ALLOW me to commence these remarks by saying how deeply sensible I am of the honor of addressing this representative gathering of American electrical engineers. Thoughtful Europeans, as Lord Bryce well said, have begun to realize the increasing influence of this vast country in the affairs of the world, and the splendor of the part reserved to you in the development of civilization. A brief visit to your hospitable shores has been an inspiration and has enabled me to appreciate, in some small measure, the freedom of your thought, and the breadth of your conceptions. Such is the grandeur of your outlook that I can but echo what was so beautifully expressed by one of the orators at the recent Harvard commencement exercises, namely, that the world needs you and the world will heed you if you but acquit yourselves as men!

So much has been written regarding standardization, and the art has become so necessary to progress, and is so familiar to many of you, that I cannot hope to do more than focus your ideas on a few of the more important aspects of the subject. I shall also try to bring into prominence some of the points connected with the development of engineering standards in Great Britain, which I hope may be of interest, more especially as in order to minimize overlapping and obviate piecemeal methods, the question of co-ordinating the various individual methods in one homogeneous body is occupying the serious attention of competent authorities in this country.

In matters electrical, national and international standardization are so intimately connected that it is scarcely possible to speak of the one without discussing the other. Indeed, international standardization, a barbarous term it is true, but a difficult one to supplant, would seem to be the natural development from the experience gained in the practical application of national standards.

It was stated on one occasion, I remember, that the earliest

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record of standardization was to be found in the introduction of the Greek alphabet initiated by Xerxes and which was refused by China and Russia. However that maybe, the most notabled step in the realization of engineering standards, in so far as Great Britain is concerned, was in 1841, when Sir Joseph Whitworth introduced his standard screw thread. When urging the necessity for standardization, he illustrated his argument by mentioning that candles and candle-sticks were in use in almost every house, and nothing could be more convenient than for the candles to fit accurately into the sockets of the candle sticks, which they seldom did. The lesson taught by his illustration lies at the root of standardization and necessarily carries with it disadvantage to the few for the advantage to the many.

Then we come to the Standards Committee of this Institute, of which Prof. Crocker was the first Chairman, which reported on electrical standardization in 1898. The splendid pioneer work accomplished by that committee has been an incentive to many others and whatever form the proposed central organization may take, the Standards Committee of this Institute will doubtless retain intact its distinctive character whilst supplementing and extending its activities.

Several factors, including keen competition from outside, the legitimate demands of labor for a higher standard of living, coupled with the desire of capital for a better return, have compelled the electrical, in common with the whole engineering industry, to introduce modern order and system into all its methods of production. Former individualistic methods have been forced to give way to co-ordination and collective effort. It is, in fact, co-operation which gives the highest value to individual effort. This, if voluntary and not compulsory, will help to maintain quality.

Now, these improvements which have already resulted in marked benefits, must not only be maintained, but continually added to if the full advantages are to be reaped. Inevitably the necessity of standards to which the products of the workshops may be referred, has manifested itself just as much as fixed standards of weights and measures.

Of course, the individual gain, economically, in private workshop standardization is acknowledged great to the producer for it tends towards interchangeability of working parts, lessens maintenance charges and stores; crystallization, however, which would tend to impede and in some cases stultify progress must

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be jealously guarded against if monopolies are to be avoided and the purchaser is not to be deprived of the benefit of competitive effort and inventive genius. If, therefore, through some comprehensive centralized body, the users and producers alike can be persuaded to accept an agreed standard, the community interests of buyer and seller is thereby realized and a high average efficiency secured. Generally speaking, satisfactory standardization, whether national or international, has usually been arrived at not by one section of the community imposing its opinions on the other, but rather as the result of co-operative action on the part of all concerned.

Experience has clearly shown that such procedure does not lower the standard, but if anything tends rather to raise it. It reflects, in effect, the consensus of opinion as to what constitutes best modern practise. Such standardization is only arrived at by common consent of the governed who take full part in the discussions and in the initiating and working out of the actual details of the specifications to be recommended for public use. This is one of the chief reasons why the work of the Engineering Standards Committee of Great Britain is so widely adopted—because of the utmost care is taken, at the very outset, to insure that all who have or could possibly have any interest in the proposed standardization shall have an adequate representation on the Committee drafting the recommendation. This representation is usually effected through the recognized societies and associations of the particular engineers or trades concerned. Such methods register the views of the experts in manufacture as well as those intimately acquainted with the conditions under which machinery and apparatus are employed in every day service.

Undoubtedly, mutual concession and ultimate agreement between the parties interested tend towards uniformity of practise, avoidance of waste, elimination of harsh and unnecessary conditions, and last, but by no means least, brings about a feeling of mutual confidence, such as could not be realized by isolated action on the part of either, however honorable and straightforward it may be.

Again, though much time and labor be occupied in preparing such standard specifications, additions and emendations demanded by experience and new developments must be provided for, and consequently, the specifications must be reviewed annually and thus eliminate undesirable stereotyping of pro-

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cedure. Such revisions must also be promptly and efficiently dealt with. The standards should have no other authority than that of commom consent. In fact, it is public opinion which gives them their dynamic force, and all progress would be arrested if there was a possibility of their being enacted into statutory law.

The initiation in 1901 of the British Engineering Standards Committee, the greatest private voluntary effort of the kind, is due to Sir John Wolfe Barry, K. C. B., whose name is a household word amongst British engineers. His commanding influence in the engineering world, and the deep respect in which he is held by the whole profession has probably been the greatest factor in bringing this organization to its present unassailable position. It had a small beginning, but has increased in scope and efficiency till today its influence is felt and its specifications acknowledged and worked to throughout practically the whole of the Empire. Its main committee, or Senate, is composed of the official representatives of the five leading engineering institutions; to this committee falls the whole administration of the work, the raising of the necessary funds, the controlling of the expenditure and the ratification of all reports and specifications presented by the various sectional committees prior to publication. The sectional committees are instituted by this main committee which appoints the respective Chairmen. Under this main committee there are some 80 sectional sub-committees and small panels, the membership being between 500 and 600 The sectional committees consist of representatives of the various government departments, consulting engineers, manufacturers and users, as well as representatives of the technical societies and trade associations interested in or affected by the subjects under consideration. The sectional committees, and in some cases the sub-committees, decide the broad lines upon which the specifications are to be drawn up and then delegate the working out of the preliminary details to a sub-committee or panel. If necessary, evidence is taken, the advice of experts is sought, and in this way all parties are consulted and have a proper voice in the initial proposals, thus avoiding much subsequent friction which might otherwise occur.

The specifications of the committee find an increasingly wide adoption, being more and more substituted for the various government and municipal specifications hitherto employed. They deal with the main technical clauses, leaving questions of contact to be dealt with by the purchaser.

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The electrical section of the committee, which forms an important part of the whole, is under the able chairmanship of Sir John Snell. It has recently been entirely reorganized, and is now *ipso facto* the British National Committee of the International Electrotechnical Commission, or the I. E. C. as it is called. Thus the national and international interests of the British electrical industry are under one organization with increase of efficiency in every way. Dr. R. T. Glazebrook, C. B., is the chairman of the committee when I. E. C. matters are under discussion.

In drawing up industrial standards covering electrical machinery and apparatus, experimental investigations frequently become necessary in order to establish the facts underlying the principles involved, and it is in this connection that the National Physical Laboratory has been and is so conspicuously useful to the Standards Committee. It is in effect our official testing bureau, and our ultimate authority, and it acts in an advisory capacity in practically all the work. The success of the British Standards Committee is due in large measure to the energy, foresight and ability of Mr. Leslie Robertson, the Chief Secretary, whose geniality and intimate knowledge of men and affairs have enabled him to cope successfully with problems many another would have hesitated to undertake. Going on a Government mission he perished with Lord Kitchener on June 6th last, an irreparable loss to us all.

The commerce of the world, due to the wondrous development of communication, has, one might almost say, in spite of the artificial barriers set up by the different nations, become more and more international. It is, of course, inevitable that the standardization rules for electrical machinery in use in the various countries should differ in detail because conditions of manufacture necessarily differ and so influence the rules. Yet the method of ascertaining the actual rating of a machine, paper rating one might almost call it, so important to the prospective purchaser, especially when separated from the maker by long distances, as is often the case, should surely be identical in all countries, since it depends on the physical and mechanical properties of the machine, and is not a question of geographical position. This is peculiarly the work of the I. E. C.

Theory and practise are perhaps more closely allied in electrical engineering than in any other applied sciences, and it is therefore, important in the application to industrial purposes

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of the laws of electrotechnics, that the rules which form the basis of technical specifications and consequently of commercial contracts, should be as free as possible from ambiguity and complications, yet at the same time sufficiently definite and comprehensive to insure a satisfactory means of comparison between the machine supplied and the standard.

The problem is, however, more intricate than that of dealing with simple pieces of mechanism, for it involves the consideration of the peculiar properties of the materials forming the essential portions of the machine. For instance, the conductivity of the copper or the permeability of the iron can be measured with substantial accuracy and, what is more important still, without the portion tested being destroyed or damaged. The mechanical strength of the materials also can be estimated with sufficient accuracy from the result of definite and easily carried out tests on samples of the materials, with almost complete assurance that the bulk material will have the same properties and therefore behave in the same way as the samples tested. These particular properties are, in fact, of such a nature that they can be specified with precision, and moreover, are not appreciably affected by the elements of time. When the question of the insulating materials, however, is considered, the problem is of course, very different, and one can but acknowledge that owing to their inherent properties, the insulating materials employed at present, come into an entirely different category. They are governed by no well-defined laws, as in the case of the copper and iron, their properties are variable and alter largely for very small changes in the conditions of manufacture, as well as those under which they are employed in the completed machine. The resistance they offer to the passage of the current constantly changes, and tests on samples are, therefore, not very satisfactory, as varying the length of the test may give results differing considerably in magnitude. One of the most important problems, therefore, is the settling of the limits which it is considered necessary to impose in order to insure that the principal causes of destruction of the insulating materials, the heating combined with the time element, shall be kept well within safe limits.

A clear distinction exists between an "international standard of quality" and an "international rating." The international acceptance of the former has already been brought about by the adoption, by the I. E. C., at its Berlin meeting in September,

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1913, of certain limits of observable temperature applying to the materials in general use today. But these limits do not offer a means of comparing directly machines from various sources, since they would not necessarily have the same temperature rise. No international decision has yet been arrived at in regard to the value of the cooling-air temperature to be associated with the upper limits already adopted, the commission wisely preferring to adhere to its rule of not taking action on any important question except on a four-fifths majority of the countries registering their votes. The wisdom of this procedure has been amply justified on more than one occasion, and although the advent of the war has unfortunately resulted, in so far as international standardization is concerned, in what might be termed a state of suspended animation, there is every reason to anticipate that the delay thus enforced will not adversely affect the solution of this particular problem.

However, there are very good grounds for hoping that the temperature rise recognized as standard in America and Great Britain will ultimately be accepted throughout the world.

It is evident also that the standardization rules in use in the various countries will tend to grow less divergent in proportion as the work of the I. E. C. progresses, and although the international rules are not intended to supplant those employed locally, they cannot fail, when issued, to be of material assistance to buyers and sellers of all nationalities. In addition to, or rather collaterally with, the rating of machinery, the I. E. C., through properly constituted special committees, has under consideration several other matters which come under the general heading of nomenclature and symbols. The work accomplished, so far, in these directions, may by some, be considered somewhat academical, but it should not be overlooked that international symbols, if widely adopted as they deserve to be, will greatly assist in the reading of foreign technical works, and that international agreement in regard to nomenclature, immensely difficult as it is, and calling for so much personal sacrifice of long-cherished conditions, will be of the greatest value to the industry generally. Also the subject of graphical symbols for electrical plans now being studied will be of considerable assistance in foreign tenders. Experience shows that the utmost caution is necessary in all international questions, and that nothing is to be gained by forcing a vote on a point not yet ripe for decision. One may hope with confidence that when

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peace reigns once more in distracted Europe, industry will be more than rehabilitated, and the electricians of the world fully appreciating, as they have, the potentialities of such co-operation, will continue their work so well begun.

I cannot close this brief review without paying a tribute of love and respect to the father of the I. E. C., Col. R.E. Crompton, C. B., its Honorary Secretary, to whose enthusiasm and ceaseless energy the commission owes its very inception. He has been a tower of strength at all times, and has ever been ready with the counsel of his ripe experience to help and encourage us through all our vicissitudes. May he long be spared to us!

I should like also to record my appreciation of the invaluable assistance of the American Section of the I. E. C., which the Central office has so uninterruptedly enjoyed. To Dr. Mailloux, with his wonderful linguistic ability, we owe a debt it is impossible to repay. In the early stages of the movement, it was owing to the perfect ease with which he was able to explain knotty points in several languages, almost without realizing in which he was speaking, that the many difficulties connected with the launching of such an enterprise were successfully smoothed away. To Dr. Kennelly, too, I owe much for the kindly help and advice he has always so generously given me. Indeed, in times of difficulty, the American Section has never been appealed to in vain.

Laboring thus in the fullest degree for the advancement of the electrical industry of the world, it will be this close co-operation which will win the day, due, not so much to any particular individual, but rather, as Kipling says, "to the everlasting team-work of every blooming soul."

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DISCUSSION ON "STANDARDIZATION" (LE MAISTRE) CLEVELAND, OHIO, JUNE 27, 1916.

(Subject to final revision for the Transactions.)

Clayton H. Sharp: We are, indeed, very fortunate to have Mr. le Maistre with us here today. He has told us something about the work and organization of the Engineering Standards Committee of Great Britain, and of the I. E. C., but, naturally, did not say anything to us about what I might call the real *deus ex machina* of international standardization, and that is Mr. le Maistre himself. If it had not been for his extraordinary genius in diplomacy, in turning the sharp angles, in smoothing down the ruffled feelings, in finding the way out, in working with entire self-effacement, and self-forgetfulness, with the major end in view, if it had not been for the wonderful work on the part of Mr. le Maistre, the success of the entire movement would have been very questionable, indeed.

Those of us who have been to the other side to attend the meetings of the I. E. C. and of its committees, have formed a very great affection for him, and the utmost confidence in his far-sightedness, and above all, in his fair-mindedness. Now that he has come over to this country, the contact between the work of the British Committee of the International Electrotechnical Commission and our own Committee will undoubtedly be established even more closely than before, and we know we have in Mr. le Maistre a thoroughly reliable foreign connection, a go-between, if you please, whereby the concordance of the work in this country with the work in Great Britain will be assured, since he will act to each committee as an interpreter of the work of the other. We, therefore, ought to thank him for coming, and we ought to thank his broad-minded chiefs on the other side who have sent him. I am sure he will go back with the heartiest good wishes of all of us who have met him here.

Farley Osgood: I cannot say too many kind things about our English friend, Mr. le Maistre. He came here a few weeks ago, unknown personally to most of us, although well known by reputation, and he at once was a help to us in our standardization work. His assistance at the Chicago conference of the Bureau of Standards, in connection with the Safety Code, was very great and his clear explanation of the English methods of caring for this kind of work very materially assisted in our discussion at that time, and all felt that we were fortunate to have had a visit from him at this most opportune moment.

C. P. Steinmetz: I have little to add, except to say that as a member the first Standards Committee which was organized here in 1897, and repeated the next year, and as a member of all the succeeding Standards Committees and all the National Electrical Committees, until the last year, when naturally the younger generation, our pupils, took over the work, I have always been very much interested in the work of national and international standardization, though I must confess that when international standardization was started I very much doubted

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the feasibility of accomplishing many of the results aimed at, due to the difficulty of getting practically unanimous agreement, which was necessary, between all the nations, but I must confess I was greatly surprised by the relatively large amount of work accomplished.

How this was done I have only in the last day or two been able to realize, by having a chance to discuss the matter with Mr. le Maistre, and I then realized that in this work, as in many others, the result was to a very large extent the personal accomplishment of one who devoted all of his time and energy to the purpose.

Mr. le Maistre says that the work of international standardization is now unfortunately in a state of suspended animation; that is true, but during these days the world is being impulsively driven into shape for co-operation, and all standardization is based on co-operation. When this unfortunate war ends, and the nations wake up again, after finding themselves very much changed, the old idea of every one for himself will be seen to have vanished, and there will be a greater realization of the necessity of co-operation for the mutual welfare. We may well imagine that these few days of suspended animation are not lost, but that the work of international standardization will proceed with increasing rapidity and it will more than make up for the lost time, as soon as these present conditions pass.

C. le Maistre: So many kind things have been said of me by so many people that it would take a very long time if I tried to thank each one personally.

My visit here has, I have said repeatedly, been to me an inspiration. I have seen the large way in which you view the problems, I have seen the co-operative spirit so alive here; and as to the kindnesses which have been shown me by every body, by the manufacturers, the large corporations as well as the smaller manufacturers, who have done so much for my physical comfort as well as for my mental instruction, I can only say I go back to London with a feeling that I really have been accepted as one of your family.

Words are very poor conveyers of thought, and I could not really express to you these feelings of unspeakable gratitude I have for having had the privilege of coming to America and of knowing something of your institutions, and of meeting so many men, so eminent in our profession, but, at the risk of repeating myself, I say that I hope that, at least in some cases, that these friendships will not be like the high-tension spark, but more like the continuous current.

Due to the rapidity with which communications are increasing in proficiency, the world is becoming more and more one nation, and it is by these meetings that we are gradually becoming more highly cosmopolitan in the truest sense of the word. We get our rough edges knocked off and begin to appreciate other people. I am sure my own Committee will appreciate very highly, indeed, the reception which their delegate has received here, and the very substantial co-operation that there has been between our nations.

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I can say that I have so many friends here that I do not feel that I can mention one without neglecting a very long list of the others, and therefore, gentlemen, all that I can say is that I thank you very much indeed.

C. A. Adams (communicated after adjournment): Not having been present during Mr. le Maistre's address, I am taking this opportunity of expressing myself on two phases of this subject which are close to my heart.

The first of these has to do with the very broad, one might almost say philosophic, aspect of standardization.

The world is today in the throes of its greatest war. But there are other types of conflict between nations or more often between the various groups within nations, which are always with us, and whose possibilities in the way of producing real human unhappiness and misery are quite as great in the long run as those of a war even of the magnitude of that now in progress.

The more one studies such conflicts the more one becomes convinced that one of the most important causes is the lack of mutual understanding and appreciation as between the various groups involved. This lack of understanding is in turn due to the various barriers which separate the groups, and one of the greatest of these barriers is the lack of a common and accurately understood language, this last word being employed in its broadest possible sense. For example, contemplate the large number of disputes based upon different interpretations of the same document, even when the document has been drawn by experts with the greatest care, and with the special aim of avoiding vagueness. How much more difficult it is to avoid misunderstanding between two groups having widely differing life experiences, customs and standards, or again between peoples of different traditions and speaking different tongues.

One of the most important functions of any Standards Committee is to establish within its own field just such a precise and compact language which will be acceptable to all concerned, *e.g.* it is obviously of the utmost importance that we all understand the same thing, when we say that an alternator has a continuous rating of 1000 kv-a. Yet it took your Standards Committee many years to produce a satisfactory and generally acceptable definition of "Rating", and a considerable part of our present rules is devoted to the defining and elucidating of this one word and to explaining how the rating of a machine can be checked by test.

The process by which this result was obtained is in a large degree typical of all the work in this field, and at the same time illustrative of the chief point of these remarks.

First the various groups involved were brought together; they exchanged data, experiences, theories and points of view; until apparent conflicts of interests disappeared through a process (sometimes stormy) of mutual education. In other words they finally came to an understanding through the evolution of a

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common language. That this language is still imperfect is obvious, but it serves a very useful purpose even now, and will doubtless grow in usefulness as it slowly evolves.

Taking the next step, into the international realm of engineering standardization, we find the same process at work; and although a little more slowly, yet to the same end; a gradual evolution of an international understanding, a substantially universal language, and a cordial spirit of co-operation, which if it extended only to the confines of the particular realm of human endeavor here under discussion, would nevertheless be an important factor in the hastening of that time when the term "human brotherhood" will apply beyond the borders of each particular little group.

To be sure this international movement appears to be temporarily arrested in certain quarters, but I for one, am confident that the engineers of the waring nations will be among the first to set aside partisan feelings for a broader common sense spirit of co-operation.

This brings me to my second point, which is the personal one. In all of this work where representatives of the various groups get together, the personal element is a most vitally important one. One needs the courage of his convictions, but the narrow minded partisan must in the long run give way to the broader co-operative spirit. Many of the chasms of unfriendly misunderstanding which develop in all fields of endeavor might easily be bridged if there were more of this spirit abroad.

In this connection I cannot refrain from adding my tribute to Mr. le Maistre. He came to us as delegate of the Engineering Standards Committee of Great Britain; he sat with us in informal conference or in formal meeting day and night in several periods aggregating two solid weeks; he presented the suggestions of the British Committee in the broadest possible spirit, but did not confine his discussions to that part of the subject; he entered into the spirit of our meetings and became one of us, giving us generously of his time and experience; his personal assistance was of such an order that we shall hereafter feel any revision of our rules incomplete without his suggestions.

This is the kind of getting together, of co-operation, of learning each others' language, of building up a friendly understanding as contrasted with an unfriendly suspicion, which was referred to in the first part of these remarks. It is work of this kind which breaks down the barrier of misunderstanding, and draws groups and nations closer together.

The engineering profession, not only in Great Britain but the world over, is thus to be congratulated in the recent appointment of Mr. le Maistre as General Secretary of the Engineering Standards Committee of Great Britain, and the electrical engineering profession is to be specially congratulated in still retaining his services as General Secretary of the International Electrotechnical Commission.

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DISCUSSION ON "THE RESTORATION OF SERVICE AFTER A NECESSARY INTERRUPTION" (RICKETTS), CLEVELAND, OHIO, JUNE 27, 1916. (SEE PROCEEDINGS FOR JUNE, 1916.)

(Subject to final revision for the Transactions.)

Harold Goodwin, Jr.: These relays presented by Mr. Ricketts in this paper are most interesting, and the results of the operation of the system of the Baltimore Consolidated Gas, Electric Light & Power Company, particularly in connection with the current received from Holtwood show their very great efficiency.

There is one particular point to which I wish to call attention and that is where the text reads: "During the operation of the device, the induction motors will slow down and come back to normal speed, but the relays controlling them should be set for a rather high current, say 400 per cent load, to prevent them from tripping before the motors are up to speed." That is all right, I think, if the motors are all equipped with relays, and if all of the motors were in power plants handled by operatives, but as the system reaches out and reaches down to the smaller users of current, motors are connected without relay equipment but simply fuses. Were all the fuses capable of carrying 400 per cent normal current they would fail in their original purpose of protecting the motor under abnormal conditions and the distribution system under starting conditions. Without going into details let us note that the original purposes of a protective device need serious consideration before an extreme setting is adopted.

R. F. Schuchardt: Fig. 1 shows a balanced relay protection, regarding the efficacy of which I can give testimony. On the system in Chicago we recently had a breakdown in the armature coil of a generator protected with a scheme very similar to that shown by Mr. Ricketts. The generator switch and the field switch were very promptly opened by the relay and the damage in the generator was limited practically to a single coil. The value of the relay in this operation can be better understood by comparing with similar breakdowns which occurred years ago before reactors were installed, the generators having no relays of any kind. In all of these cases the operator, who has a clear view of the generators, saw the flash and very promptly opened the switch but almost invariably all coils were damaged.

The very interesting scheme described, in which the field circuit is opened during certain cases of trouble, is apparently applicable primarily to overhead transmission lines and considerable modification would be necessary to apply it to underground systems. The arrangement shown in Fig. 10 can be applied to distribution circuits almost universally and is of particular value where these circuits are overhead and where disturbances which cause the switch to open are often only momentary. It would be worth while to work out a modification

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of this scheme applied to an automatic pole type switch connecting branch circuits, thus reducing the extent of interruptions and thereby still further improving the high record of continuity of service which is now enjoyed by modern systems.

H. R. Woodrow: I agree with Mr. Ricketts regarding the installation of relays on generating circuits. As we have found the burnouts in generators rare, and the reliability of present automatic devices somewhat questionable, we have considered it wise to keep the generator switches non-automatic.

In the generator balanced protective arrangement described in the paper, a loose cable contact, or a slight difference in current transformer characteristics, might cause the relays to operate on straight overload. I would like to inquire if this has ever occurred on any of the systems using this form of protection.

The wonderful improvement in sensibility and reliability of reverse power relays looks promising for an application in making generator switches automatic.

I would like to ask Mr. Ricketts a question regarding the opening of the generator field circuit. In our experience the opening of a generator field switch has always caused a heavy voltage disturbance on the exciter system. Quite recently a single-phase short circuit occurred in a generator which produced high alternating currents and voltages in the field circuits, causing a severe disturbance on the whole excitation system and control system, which happened to be connected at that time to the exciter bus.

In cases where a considerable generator field resistance or long cable runs are in series with the field circuit, an opening of the field circuit will undoubtedly cause a heavy voltage disturbance in these circuits.

I would also like to inquire if there is any provision made for the speed control when the field circuit is opened? That is, any provision to keep the speed down, as the speed will rise very rapidly if the field circuit is opened and the load is taken off.

Also, when the generators are thrown back in service, what provision is made to prevent arcing at the commutators of the exciters? In one case that I know of, it was attempted to restore service in the manner described, which resulted in serious damage to the exciters by arcing across the commutator. In this case, however, there was no battery floating on the excitation bus.

In general, I do not believe the principle of restoring service as described would be very advantageous to a large concern where there are a large number of underground cable lines, as we very rarely find, in such cases, a disturbance on the system which will clear itself if the voltage is taken off.

We have used to good advantage, on overhead lines, the principle which the author refers to in Fig. 10, but with hand operated switches. The switches are automatic and they are immediately thrown in once or twice by hand, after they have automatically opened; and in cases of the principal circuits,

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the operators are instructed to throw the switches in at least twice after they have automatically opened during a lightning storm. In over 50% of the cases the service is restored without further disturbance.

I wish to bring out one point as a warning in accepting this method of restoring service; that is, this method cannot be used unless the switches are completely automatic. That is, unless they will immediately open if thrown in on a short circuited feeder.

E. T. Street: I notice that the scheme devised for protecting the generators will multiply very largely the number of current transformers on the system. The current transformers on our system have given us a good deal of trouble, and I am of the opinion from what I have read, and I ask if it is correct, that the burning out of one current transformer would shut down the entire station until the transformer was found and isolated. If that is true, I am afraid that the scheme will increase the liability of serious trouble from a small cause.

George A. Burnham: There is one point which might be worthy of consideration, in reference to the elimination of potential on the system to reduce the trouble as a whole, caused by a fault in one of the generators.

It would appear to be a disadvantage to reduce the potential to zero for the length of time which Mr. Ricketts states, in view of the fact that in nearly all of the industrial plants either the individual switches which control the motors or the service switches are equipped with no voltage release of the instantaneous type and the loss of potential at these attachments would undoubtedly disconnect a very large portion of the load on the system.

The arrangements which Mr. Ricketts has described, could, it seems to me, be utilized more effectively and with less liability to interruption of service, if, instead of opening all of the field switches of the generators on the occurrence of the fault in one generator, the balanced relay tripped only the switch of the faulty generator and then allow the movement of the generator switch to disconnect the generator field switch subsequently or simultaneously. This would reduce the potential to zero on the faulty generator instantly after it had been disconnected from the bus and prevent further destruction. It could easily be arranged so that the aforementioned generator field switch would be non-automatic, except when rendered automatic by the operation of the balanced relay, by the addition of an extra contact on the relay which would be connected in series with a circuit closing switch on the main generator breaker. With this arrangement it would appear to me that the faulty generator could be very satisfactorily disconnected and the potential removed from said generator in order to eliminate further destruction, without it being necessary to remove the potential from the entire system.

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John B. Taylor: From the discussion it appears that some members approve certain features of the automatic system, but doubt how far operating and other conditions may be comparable to the systems with which they are more familiar. Devices such as these cannot be applied indiscriminately to any existing system, since much depends on the character of the load; the ratio of cable mileage to overhead lines, the transmission and distribution voltages and the principal causes of interruption.

L. N. Crichton: The part of Mr. Ricketts' scheme that appeals to me most is the service restorer device. Mr. Ricketts has taken quite an active part in the advance of the automatic sectionalizing and it is fitting that he should turn his attention toward methods for restoring service after, for any reason, a circuit has been disconnected.

I recently had the pleasure of seeing that automatic service restorer device in operation, and it was quite remarkable as to the rapidity with which the various pieces of apparatus were put in motion, although there was no induction motor or any load of that kind at the point where I saw the test being made, and I doubt very much whether a man at some little distance away from the motor would have known there had been any momentary interruption of service at all.

It seems to be a scheme particularly useful for high voltage lines distributing small amounts of power, where the lines extend out in the country for a good many miles, and where lightning conditions are such that if a scheme of that kind is not adopted reliable service could not be given to a good many classes of service. I believe there will be quite an advance in the art of giving continuous service by the use of this device.

Joseph T. Kelly, Jr.: With regard to the point which Mr. Goodwin made, relative to the 400 per cent set of motor relays, I can only say, that the system has been in operation now for something over two years; and we have never heard of a case of trouble of that sort. In fact, as was stated here a moment ago, in most cases—I suppose very close to one hundred per cent of the cases—customers never know that there has been an interruption on the feeder service. Looking at the lights, there is a barely preceptible blink, and looking at a motor it is almost impossible even though watching for it, to notice that there has been any slowing down in the motor at all.

Regarding the application of the scheme to hand-operated switches, so far Mr. Ricketts has not been able to do much work along that line. As a matter of fact, there is one remaining substation of the Consolidated Company equipped with hand-operated switches, and at the present time work is under way to replace all that switchboard equipment with electrically-operated switches equipped with this system, and when that is done all of the substations of the Consolidated Company will be equipped in this manner.

As to the opening of the field circuit causing a disturbance on

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the exciter system, the point mentioned by Mr. Woodrow, all of our exciters have storage batteries connected with them, and that, doubtless, makes a difference. We do not have any trouble whatever due to the opening of the field switches.

As to the matter of the application of the device to underground cables, of course, when an underground cable breaks down usually the trouble is not of a nature, which clears itself when the potential is cut off. It is usually a permanent breakdown, and consequently though removing the potential and then re-applying it, the trouble would still be present. However, there are cases in which the cable heals itself or will not reestablish an arc when the arc has once been broken. In any event, the momentary application of voltage to the cable cannot do any harm, because the whole cycle takes place in about 7/10 of a second, and there cannot be a sufficient flow of current into the fault in that length of time to cause disastrous results, so that even on an underground system there can be no harm in using this system, and to that extent, I would say, it is not limited to the overhead system. In fact, on the Consolidated system, every feeder going out of a substation, goes out under ground for a greater or less distance, and the automatic opening and closing device is applied to these feeders impartially.

If the trouble is on the overhead, and transient, or if the trouble is on the underground, and clears itself, the system works. Of course, if it is a permanent short-circuit the system will not work, and in that case, after the predetermined number of automatic closings the switches will remain open. In our system they are set to close three times, and if they open the fourth time the switch remains open until manually closed.

Mr. Sweet raised the question about the burning out of current transformers. As I understood it, that was in connection with the first scheme for protection of generators. In that case, there are two current transformers, one on each side of the winding of the generator—if either of these burned out, there would, without doubt, be an unbalanced current in the secondaries; in other words, the current in the two current transformers, the one faulty and the other not faulty, would not be maintained, equal, and consequently the relays would operate to cut that generator out of service, including the transformers connected to it, and the system would not be interrupted.

Mr. Burnham raised the point about trouble in a generator causing an interruption on the whole system. That would not be the case because as shown in Fig. 1, in Mr. Ricketts' paper, covering the case of trouble in a generator, if trouble occurs, that generator will be disconnected from the circuit without opening the fields on the rest of the apparatus.

Replying to Mr. Taylor regarding the system; that of the Baltimore Consolidated Gas, Electric Light & Power Company is a 2300/4000-volt four-wire distribution system, the transmission voltage between substations being 13,200 volts with a

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grounded neutral, and the field-opening device is also used on the 60,000-volt transmission line from the generating station of the Pennsylvania Water & Power Company at Holtwood, Pennsylvania, to Baltimore, although, as Mr, Ricketts mentions incidentally in his paper, in that case the timing device is set for four seconds instead of two seconds, as used in the Consolidated system. The reason for that is that the Pennsylvania Water & Power Company also uses the Nicholson device and Mr. Ricketts' field opening device is so set as to give the Nicholson device a chance to operate first, and then if that fails to clear the trouble, or does not succeed in entirely clearing the trouble, then the field opening device will operate. As Mr. Ricketts points out, that delay of four seconds imposes very much more severe conditions in restoring service.

I have not in mind figures as to the relative amounts of underground and overhead feeders in our system—every feeder, as I said a moment ago, goes out from the substation underground, and the overhead portion is limited to the acutal distribution portion of the feeder; many of the feeders distribute entirely underground, and the system is applied impartially to all feeders. The capacity of our generating station at the present time is approximately 35,000 kv-a. nominally, and will be increased within the next couple of months to about 70,000 kv-a.

I might say, in closing, that the proof of the pudding is in the eating. This system was first applied to a suburban substation at which no operator is kept, something over two years ago, and it has operated with the greatest satisfaction. When a feeder trips out, a relay closes a contact and rings an alarm bell in the office of the district foreman, about three-quarters of a mile distant. That bell may either make two or three, or even one short indication, or it may make three short indications and then continue to ring. In other words, if a feeder drops out and restores at once, and stays in, the alarm bell will so indicate. If it drops out twice and restores itself, the same. If the feeder stays out, the alarm bell continues to operate. So with no operator within three-quarters of a mile this substation is taken care of by this device, and it has been in satisfactory use there for about two years and a half. About one year ago five other substations were equipped with this system, and at the present time the apparatus is ordered with which to equip the last of the substations of the company.

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DISCUSSION ON "STUDIES IN LIGHTNING PROTECTION ON 4000-VOLT CIRCUITS" (ROPER), "EXPERIENCE AND RECENT DEVELOPMENTS IN CENTRAL STATION PROTECTIVE FEATURES" (POLLARD-LAWSON), "PROTECTION OF HIGH-VOLTAGE DISTRIBUTION SYSTEMS BY ISOLATING TRANSFORMERS" (RIDER), CLEVELAND, OHIO, JUNE 28, 1916. (SEE PROCEEDINGS FOR JUNE, 1916).

(Subject to final revision for the Transactions.)

E. E. F. Creighton: Of Mr. Roper's paper I will say, first, that I think it is a piece of scientific work on a magnificent scale of very great value to the electrical industry. It differs from most of the work, in that it is finished. The whole electrical industry is benefited, new principles have been proved and some principles have been disproved and discarded. There will be a chance to get better service on the part of those who wish it, and better lightning arresters. From my own standpoint I wish to acknowledge a great benefit derived from Mr. Roper's work in that it made possible to choose between several factors of design of lightning arresters, and thereby improved the product for everybody.

Apparently, from the way in which Mr. Roper has presented this paper, it was a very simple affair, but I assure you that the thousands of data which he has collected were in a very chaotic condition, and it required the highest sort of analysis in order to bring some sort of order out of this chaos. All sorts of antagonistic results were obtained—they are all simple enough now after Mr. Roper has analyzed them and told us why they are antagonistic, and he has been able by that method to discard certain parts and draw proper inferences from other parts.

I want to pass on now to the other papers, not as a discussion, but simply to point out certain factors. Take the next paper by Mr. Pollard and Mr. Lawson—this is a paper of a different character. It is a record of progress with new apparatus. The modest presentation of the subject gives an inadequate idea of its importance.

It seems to me a very good time to bring out the importance of the arcing ground suppressor in the problem of grounding the neutral. This discussion, by silence, yesterday, related to one of the very big interests, the telephone interests, and the possibility of interference between the power circuits and the telephone circuits. The interference, unfortunately, is all in one direction, since the telephone circuits have such a tiny amount of power they cannot in any way interfere with the power circuit.

These are two big public service interests in which we are all interested and which we want to see successful, and this problem is not one for the lawyers, but one for the engineers. If the engineers cannot get together and decide what can be done to minimize the effects of interference, the law court is a poor place to go, and the spirit which has been manifested on the two sides of this particular case—I was able to see it because I was brought in as a third party in the discussion of the value of the arcing

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ground suppressor in avoiding interference—gives hope that this interference may be eliminated in the future. There were cases of interference where the telephone girls received very bad shocks from the heavy grounds that were induced in the telephone line, and we were looking for some method of avoiding them.

The greatest cause of interference and the widest spread of interference between power lines and telephone lines is due to electromagnetic induction. Electrostatic induction is very bad in the case of a telephone line being near the power line, for example, if it is placed underneath or on the same pole with the power circuit. However, by placing the telephone line on adjacent right of way, the electrostatic troubles are reduced to a negligible value which the telephone company can take care of without trouble. When, however, we take into account the electromagnetic troubles, it becomes almost impossible to prevent interference. Take this one case of the Public Service Electric Company where the grounding current for the total system is only 60 amperes. The radius or distance which 60 amperes will influence the parallel telephone lines over is rather small. By grounding the neutral, however, that 60 amperes is turned into several thousand amperes, and the distance over which the electromagnetic force will influence the telephone lines is greatly increased.

One of the strongest factors in maintaining a non-grounded neutral system is by the use of the arcing ground suppressor, and if Mr. Osgood should speak on the subject, he could tell you a lot concerning the studies which they have made relative to the interference, and the conclusions they have come to regarding the use of the non-grounded neutral.

The suspension insulator problem is one which will probably not be solved for some time to come. I wish I had the time to note the relations of these big corporations to the solution of the problem. In the case of the Commonwealth Edison Company it takes a broad spirit to come to the conclusion that Mr. Roper gives in his paper—that with all the work that was done, that with all the thousands of dollars that were spent, the direct gain in the saving of dollars and cents was nil. The whole thing turns on the point that it gives better service. In the same way with regard to the investigations of the Public Service Corporation of New Jersey—the service has stood above everything else.

When we come to the insulator problem, we have a number of comparatively small companies building insulators and reducing the price of the insulators at a time when a big corporation would have increased the price and put the difference into experimental work. There is no saving today in having a cheap insulator. If the cost of the insulator could be increased fifty per cent, and it would do away with the line troubles, it would be a great saving to the transmission engineer, but it seems impos-

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sible for the smaller concerns to get together and carry on such an investigation.

C. P. Steinmetz: Reverting for a moment to the individual papers, it is interesting and significant in Mr. Roper's paper to note the conclusion that although 100 per cent protection is not warranted because the cost of perfect protection is somewhat greater than the cost of repairing damage to transformers resulting from less perfect protection, nevertheless, he introduced 100 per cent protection as quickly as possible because reliability is the all-important question. Unfortunately, it is not every electrical system which takes that attitude; it is far from being the case. There are, indeed, many that have not reached the high standard which the world will demand in the future, but those which have adopted this standard include I may say, practically all of those operating systems that are the descendants of the old Edison three-wire d-c. system.

In Mr. Rider's paper is another interesting and significant statement, namely, that the non-grounded delta system has been preferred. Now, there are many engineers, especially in the West, whose experience has been different, and who from their experience prefer a grounded Y system of transmission, but the explanation of this apparent difference of opinion is contained in Mr. Rider's paper in the statement that one requirement is at all times preeminent, namely, supplying continuous service over the three wires. (It is brought out, as sharply as it can be, that the relation between the isolated delta and the grounded Y is that of reliability of service as compared with cheapness, and where it is desired, at the least investment, to get some kind of service, there the grounded wire has the advantage, because with the line insulated to a lesser degree this system gives less trouble. But where reliability first is the predominant feature, as it must be in those great systems which really desire to change the statement that the good and old reliable is not the electric light, but the tallow candle.)

The preeminent importance of a high degree of reliability is present throughout all the arguments of the three papers, and is substantiated to some extent, by experience in establishing and maintaining such reliability. It is in reality a great social problem involving the organizing of a universal power distribution and supply by electricity, different phases of which are severally dealt with in these papers.

Mr. Rider's paper deals with one phase of it, that of country distribution; Mr. Roper's paper deals with another phase of it, that of city distribution, and the third paper deals with station control and system control. But when electrical engineering enters the field of taking over the universal power supply of the community, of the nation, they must then go beyond the old conception of trying to organize so as, with the minimum possible investment, to get the maximum immediate returns, because as soon as they undertake a universal problem, a social

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duty also devolves upon them, the duty of giving satisfaction to all.

Then also comes in the problem of not interfering with other lines, with the telephone, etc., and in taking all those precautions that will safeguard life and at the same time give maximum reliability, in short, a conception of organizing the system so that it will be a benefit to all and a harm to none. That is the fundamental requirement which is before us, and which must be the universal conception and practise before we can expect electric power to be used as the universal agent of the world's energy supply.

In closing, I wish to add only one feature to the general discussion dealing with protective devices, provided against abnormal voltage, abnormal current, abnormal frequency, etc., and that is, to mention a further protection against troubles which are needed, not in the experience with those systems which have been considered today, but rather in other systems, in smaller systems, where economy of installation has predominated, and economy of operation has followed. The troubles to which I refer, the sources of many mysterious interferences with reliability, are carelessness and dirt.

A switch is opened by some assistant operator by mistake, and is immediately thrown in again, before this is noticed. The synchronous apparatus has fallen out of step, or otherwise flashes over, and a mysterious accident has to be investigated by writing theories on high frequency, etc. Or a high voltage switch bushing, gradually becoming covered with dust and dirt, is located near a window; the window is left open admitting moisture laden air, which condenses on the dirt and a flash-over results, the lightning arrester does not discharge, and the transformer is burned up by a short-circuit. Then an investigation shows by factory test that it requires more than three times normal voltage to flash-over that bushing, hence, there was high voltage present. The lightning arrester did not discharge, although only a short distance away, and that means that this high voltage was of such extremely high frequency as not to reach and discharge from the lightning arrester. It results often in a general lack of confidence and uneasiness on the part of the operating staff.

Such things can be avoided only by automatic recording devices which would have shown there was no abnormal voltage and no high frequency present, that the accident started with a short-circuit at the bushing, and therefore the bushing was in such condition that normal voltage and normal frequency went over it. In the other instance that I mentioned, the automatic recording device showed that the switch was opened and immediately thrown in again, of which operation there was no record in the station report.

These instances illustrate what I want to bring out—I do not wish to say there are no such things as high frequency dis-

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turbances, excessive voltage, etc. They are often present, and have shown themselves over and over again. They are the most frequent and serious causes of trouble in existence, but do not let us always jump to the conclusion that every trouble is due to some mysterious phenomenon; let us also keep in consideration of the fact that the human element and the fallibility of human nature are involved, which matter is a very frequent cause of trouble, against which there is no remedy except by the use of automatic devices, that are not susceptible to human frailties or neglect, and will not forget to record immaterial incidents.

P. H. Chase: In Messrs. Pollard and Lawson's paper a brief mention is made of the split or divided conductor principle in its relation to ideal relay protection of transmission circuits. I wish to bring out a few points in connection with the methods used in the application of this principle.

What may be called the individual differential or balance method has been used for some time for the protection of transformers, generators and cables in order to secure perfect selective disconnection of faulty equipment from the system, in the minimum time. This is accomplished by entirely separating the means used for protecting each part from the means used for protecting any other part of the system, thus making the disconnection of the faulty part contingent only on predetermined conditions within itself.

This method of protection has been utilized to a great extent in England to allow the operation of the transmission system as a true network, which is the only way a transmission system covering a large area can be economically constructed and operated with the minimum liability to interruption. An interconnected system can be operated with a fair degree of freedom from interruption by the use of time limit relays of various kinds, but this protection at best falls far short of that obtained by the use of the individual differential or balance principle, and is further impaired because, particularly on a large system, the operating combinations are continually changing. As is outlined in this paper, apparatus nowadays does not require the protection but the integrity of the service demands it.

Contrary to a somewhat widespread impression, the individual differential or balance method of protection does not involve a net increase in cost, considering both investment and operating cost, when applied to a transmission system. An interconnected network allows the greatest utilization of the transmission copper at all times by decreasing power losses and maintaining voltage. Also such consolidation allows the greatest possible utilization of the most efficient generating units connected to the system, and of the diversity factors of the loads in different areas. With an interconnected system, each substation may have several sources of supply, and, in the case particularly of static transformer substations, the operating force may be decreased, or

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even eliminated, as there will be automatic selective disconnection of any faulty supply circuit without an interruption of service to that substation. These considerations, it is evident, may greatly overbalance the consideration of a possible greater investment in transmission lines and equipment.

The individual differential or balance method of protection may be applied to transmission circuits by:

1. Running external pilot wires for each line or cable. This method is mainly applicable to short underground circuits.

2. Pairing two lines or cables which have the same destination, and operating them regularly as one circuit, disconnecting it only in case of failure of either line or cable. This method is applicable particularly where existing circuits are to be paired.

3. Dividing each conductor into two parts, which normally carry equal currents. This method is applicable to new cables which are usually called "split conductor" or "divided conductor" cables.

With particular reference to the split conductor cable, the means of protection consist essentially of a differential current transformer (or its equivalent) for each phase, the current transformer having two opposed primary windings and one secondary winding, connected to a simple instantaneous overload relay, at each end of the circuit. One primary winding is connected in each split to give balance normally. However, end faults and mechanical and electrical limitations in the insulation between splits, complicate the proposition.

In case there is a fault near the far end of a split conductor cable, the relay at that end will operate due to relative reversal, and disconnect the cable; the relay at the other end evidently will not be affected unless there is sufficient vectorial unbalance between the currents in the two splits. This unbalance cannot be sufficient unless the impedances of the two paths to the fault are considerably different, or the currents are very large, or the splits are separated at the far end with a split switch. With this limiting condition, the end fault, taken care of, faults at other points of the cable present no difficulty.

The introduction of additional reactance results in the best solution, because any acquired unbalance with end faults can be readily obtained at low values of current. The use of a split switch results in high voltages between the splits, even under normal conditions, and full voltage under fault conditions. The insulation between splits must necessarily be relatively small in order to keep down the size and cost of the cable, therefore, these voltages must be avoided so far as possible.

A further protection may be obtained with reactance, that of insuring against the loss of individual differential or balance protection which might result from a fault between splits of one conductor. The chances of such a fault may be remote, but can be simply guarded against without accompanying disadvantage.

This arrangement of the reactance is called an "end" or "selec-

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tor" reactance, and consists of one small iron core reactance in each split, a total of three reactances being at each end of the cable, which cause the necessary unbalancing between the currents in the two splits with an end fault. From the one line connection diagram in the figure it will be noted that with an end fault the split currents from the far end are unbalanced because in one current path there is no additional reactance, while in the other there are two additional reactances.

Under normal conditions each split will carry equal currents, and also there will be a voltage between the splits equal to the drop across one of these reactances, which will cause unequal currents to flow in the splits in case of a split fault. Therefore, the cable will be disconnected in case there is a ground, a phase

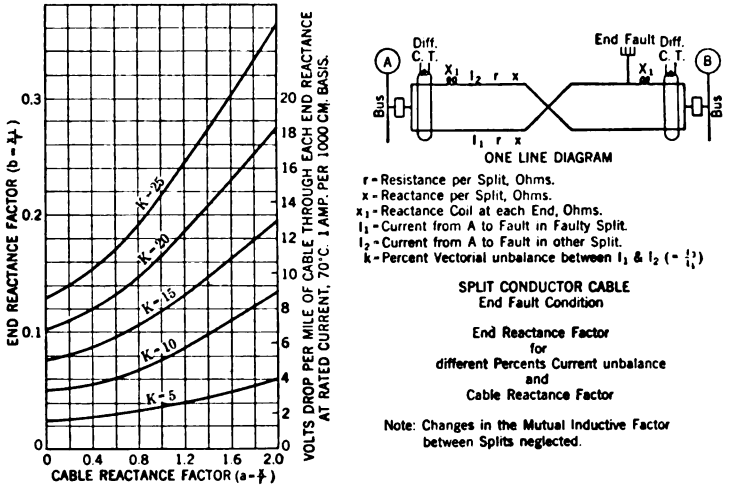
END REACTANCE FACTOR (b - $\frac{1}{4}$)
VOLTS DROP PER MILE OF CABLE THROUGH EACH END REACTANCE AT RATED CURRENT, 70°C. 1 AMP. PER 1000 CM. BASIS.
CABLE REACTANCE FACTOR (a - $\frac{1}{4}$)
K - 25
K - 20
K - 15
K - 10
K - 5
0 0.4 0.8 1.2 1.6 2.0
0 0.1 0.2 0.3
0 2 4 6 8 10 12 14 16 18 20
Diff. C. T.
End Fault
Diff. C. T.
A
B
Bus
Bus
X_1
I_2 r x
I_1 r x
ONE LINE DIAGRAM
r = Resistance per Split, Ohms.
x = Reactance per Split, Ohms.
x_1 = Reactance Coil at each End, Ohms.
I_1 = Current from A to Fault in Faulty Split.
I_2 = Current from A to Fault in other Split.
k = Percent Vectorial unbalance between I_1 & I_2 (= $\frac{I_2}{I_1}$)
SPLIT CONDUCTOR CABLE
End Fault Condition
End Reactance Factor
for
different Percents Current unbalance
and
Cable Reactance Factor
Note: Changes in the Mutual Inductive Factor between Splits neglected.

FIG. 1

fault or a split fault, and the selective protection cannot be impaired by changed conditions in the cable without disconnection.

The curves show the relation between the end or selector reactance and the resistance and reactance of the cable for different percentages of unbalance, k, under the end fault or limiting condition. The right hand scale of ordinates shows the end reactance volt drop per mile of cable for the required unbalance at full load current, on a one ampere per thousand circular mil basis. It is believed that a value of k equals 20 is a fair value to use in present practise, which means that the vectorial unbalance of the currents in the splits is 20 per cent of the larger of the two split currents.

The reactance and resistance per split are respectively double their values per conductor. For 350,000-c.m. sector cable, 13,200-volt, with 6/32×6/32-in. insulation, and 5/64-in. split insulation,

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the 60-cycle reactance factor is about 0.85. The usual values of reactance factors should range from 0.4 to 0.9 at 60 cycles, the larger cables having the greater factor. For all practical purposes it is evident that 25-cycle cables can be considered to have zero reactance. These curves give a ready means of determining the values of end reactance to use for any desired combination.

The differential current transformers should have a close balance between the primary windings, an allowable unbalance of not more than 0.1 per cent being a desirable amount, also the end reactances should have closely similar saturation curves in order to not disturb the inherent balance between the splits at all current values. The splits are transposed in present American practise near the middle of the cable only, but additional transpositions may be made to keep the balance between the splits within 0.1 per cent. This value is not difficult to obtain with present methods of cable construction.

The importance of close balance is evident when one considers the condition of a through fault with a split conductor cable feeding short-circuit current to it. The value of this current may be as great as thirty times normal. With an inherent unbalance between the splits of 0.1 per cent and an additive unbalance in the differential current transformers of 0.1 per cent, the total unbalance will become 6 per cent with thirty times normal current flowing. This unbalance naturally must be a safe amount less than that for which the relay will operate, in order to prevent disconnection of the cable.

J. T. Lawson: I would like to call attention to the table headed "Classification Troubles." This heading is incorrect and should read "Classification of Interruptions." The table is not a classification of "Troubles" of the Public Service Electric Company, but a list of the interruptions which we were unable to protect against.

Particular attention should be given to the cable failures. As you will see the cable failures in 1915 have gone up and these failures include those mentioned by Mr. Pollard; namely, the short circuits between phases.

Short circuits between phases in our system up to this time had been very few in number, most of the failures being single-phase grounds.

The failures mentioned occurred on a certain set of circuits used as tie feeders on which feeder reactances had been installed at each end.

We think the installation of feeder reactances at each end of these circuits may have had the effect of confining any high voltage condition in these cables, thus causing the failure.

Referring to Mr. Creighton's remarks in regard to interference of telephone systems by power lines, I would point out that the interference to the telephone system by any apparatus which we might install would be a serious problem to a power company. Almost all the large power companies have load dispatchers or

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system operators who are dependent for their efficient service on the use of the telephone, and any apparatus we might install in our stations which would interfere with the telephone service would seriously interfere with the service which the power company could give by the load dispatcher as he is dependent on the proper working of the telephone wires.

John B. Taylor: Referring first to Mr. Roper's paper, I understand that the system is the four-wire three-phase, 2300/4000-volt with neutral grounded, and this neutral fourth wire is grounded at but one point,—the substation. How is the fourth wire regarded as a lightning risk? Is it provided with arresters?

How are the grounds for lightning arresters made, and is the resistance tested initially or subsequently as a matter of routine.

Regarding the transformer connection boards, which have been removed, it was my impression from reading the paper that the policy of removing them was adopted before the policy of "100 per cent protection." This might mean if the "100 per cent protection" had been instituted first, the connection board would not have appeared as the source of so much trouble.

On the paper of Messrs. Pollard and Lawson, I must limit myself to calling attention to what appears a discrepancy between the table "Classification of Troubles," and the statements in paragraphs immediately before and after. The text gives the impression that the various devices have reduced the number of cable troubles, but if I read the table correctly, the figures do not show it. 25-cycle cable failures are listed as 4 per cent in 1913, 5 per cent in 1914, and 26 per cent in 1915, and in the case of the 60-cycle cables the troubles are listed as 14 per cent in 1913, 10 per cent in 1914, and 15 per cent in 1915. Attention may also be directed to the line at the bottom of the table showing yearly "cable failures per mile." It is my impression that the figures do not compare favorably with the cable records on other large systems;—for example, the Commonwealth Edison Company of Chicago, and the Interborough Rapid Transit Company of New York, operating with grounded neutral and comparable voltage. The Institute TRANSACTIONS of several years ago, if my memory serves me correctly, will show failures in the order of one per year for each hundred miles of cable, but representatives of these companies may be able to correct me if in error.* The figures given here are more on the order of one fault for every six or eight miles of cable each year.

This comparison is a pertinent point for consideration. Is this practise of putting a ground solidly on one conductor making trouble, or is there some other explanation of the relatively high number of cable failures?

The troubles on overhead lines have been reduced either by the elimination of poor insulators, the use of arcing ground

*See A. I. E. E. TRANSACTIONS, Vol. XXVI. Page 1614 for Commonwealth Edison Co. 2 burnouts per 100 mile-years. Page 1641 for Interborough Rapid Transit Co. 0.016 burnouts per mile-year.

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suppressors, or a combination of the two, but unless I misread the cable figures the record is not good.

J. O. Montignani: The Rochester Railway & Light Company operates outside of its direct-current district a three-phase, four-wire, 4150-volt grounded neutral distributing system, having a total wire length of about 1200 miles, 300 miles of which is underground. We have about 1800 transformers connected to our lines, with a total capacity of 17,000 kilowatts. Previous to the year 1911, we relied for protection against lightning upon multigap arresters placed at approximately one-half mile intervals on the more exposed lines. Not only was this quite inadequate protection, but the arresters themselves proved to be a prolific source of trouble and after most lightning storms we usually found it necessary to go out and gather up the charred fragments of a number of arresters. Invariably in burning up, the arresters fused the line wires connected to them, causing very serious interruptions to the service..

During the summer of 1911, when we first began to keep systematic records of our lightning troubles, we lost 99 transformers in thirty-one thunderstorms, being 6.1 per cent of the total transformers then installed. This alarming record decided us to remove all multigap arresters from our lines and install outdoor type electrolytic arresters at exposed parts of the system, and at important junction points on the feeders. This was accomplished in the spring of 1912, and resulted during the summer of that year in reducing our losses to 1.2 per cent with thirty-two thunderstorms. Since that time our annual losses have averaged about 1.5 per cent. That the change was economically justified is shown in the fact that basing our calculations on the reduction of transformer losses from 6.1 per cent to 1.5 per cent, the annual saving in transformers and estimated current sales amounts to a little over $2000, after allowing for interest, depreciation, and maintenance of the arresters. We have not lost a single electrolytic arrester during the four years they have been in operation, and that they are draining our lines of many severe lightning disturbances is well proven by observations we have made.

As compared with the Chicago system, our transformer losses are still very high, but the cost of electrolytic arresters would make prohibitive much further extension of that type of protection. On the other hand, we have got to be satisfied that the installation of a large number of less expensive arresters is not going to introduce greater risk of service interruptions due to their burning up, even though the loss of transformers is reduced thereby. Mr. Roper makes no mention of the number of arresters destroyed annually, and I would like to inquire if he has any record of such loss and consequent interruptions of service. I have spoken with several central station engineers whose experiences have led them to disagree with Mr. Roper's statement that:

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"Modern types of arresters comply with the specification that a protective device must be less subject to troubles than the apparatus which it protects."

The results obtained in Chicago by removing the terminal boards from transformers are very interesting and show conclusively that this is a most vulnerable point of the transformer. Our experience in Rochester has been that about 50 per cent of transformers damaged by lightning have had the primary leads burned off due to flashing-over at the terminal board. It would seem, however, that inasmuch as the terminal board serves the useful purpose of supporting and separating the leads as well as facilitating changes in connections, a remedy for its lightning troubles might be found by redesigning terminal boards to provide greater dielectric strength.

R. F. Schuchardt: Too much emphasis cannot be given to the words of caution which have already been spoken with reference to interpreting information based on experience. One must always keep in mind the essential details of the system on which the experience was obtained. For instance, reference is made in this paper to the aluminum cell arrester reducing cable trouble. This reduction is undoubtedly due to the fact that a part of the transmission system consists of overhead sections connecting to underground cables. A few years ago Dr. Creighton made an exhaustive study of the Commonwealth Edison Company's transmission system, which is almost entirely under ground, to see whether there were any surges going on in that system which might be avoided by the use of aluminum cell arresters. The conclusion arrived at at that time was that we were not justified in installing such arresters.

The connections of the Essex power station seem rather unduly complicated. I do not see why the great flexibility of the old series arc system is necessary in a high-tension generating station even when supplying a system as extensive as this.

I want to say a word in reference to Mr. Rider's paper, that consideration must be given to the kind of system to which you want to apply the isolating transformer. Undoubtedly, in many cases, for instance, in a city or village where step-down transformers must be used, it may be advisable to step-down and then to step-up again, thereby getting the isolation and also the additional advantage of regulation on the outgoing line. Or where an existing line, perhaps of inferior construction, is purchased and it is desired to connect it to the system, an isolating transformer may be preferable to wholesale reconstruction of the line: but it cannot be expected to serve as a general panacea for the ills of overhead lines. It may many times be cheaper to weed out the weak spots on lines rather than to put in the rather complicated installation of an isolating transformer with its necessary protective devices.

Peter Junkersfeld: I would like to offer a word of caution against over standardization. I refer particularly to Mr. Roper's

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paper. That development and investigation in Chicago cost us, not thousands of dollars, but many times tens of thousands of dollars. The conditions there were such that we felt, however, that this particular expenditure of money in that direction would do more in the way of further improving the service than if it were spent in some other direction. The thing which was good engineering in that case may not be good engineering in some other cases. In fact, similar large refinements in service in other communities in that general section of the country might be undesirable. It is an old saying that you must cut your coat according to your cloth, and the coat must fit the individual. The trimmings on this coat of electric service must fit the community served. In this case it was considered better to put a little more quality in the electric coat than to decrease the price. In many other communities that condition might not prevail, and that point should therefore be emphasized.

David B. Rushmore The report which we have heard gives us the result of a scientific examination of operating conditions. This is a great advance over anything which we have had in the past and offers great promise for future study. In order to make an investigation thoroughly scientific, the factors must be known quantitatively as well as qualitatively. This means that sometime in the future we must understand the quality and magnitude of the lightning disturbances involved.

With all its disastrous results, it is interesting to know that lightning is of some benefit. It is estimated that at least one hundred million tons a year of nitric acid are formed by the lightning discharges, and this is carried to the earth by the accompanying rain. On this source we are very largely dependent for the supply of nitric acid which is such an important part of the food of vegetable life and, indirectly, of animals.

D. W. Roper: We do not use the neutral wire for overhead lightning protection. Our neutral is grounded at each substation. At each transformer where an arrester is installed on the outer wire an arrester is also installed on the neutral wire. A ground rod is used for the ground connection. In Chicago, there is no difficulty in securing good grounds as the water level is only a few feet below the ground level.

The load in Chicago on the underground cables does not operate quite as well as the figures given by Mr. Taylor would seem to indicate, but excluding burnouts due to external causes, such as a pick being driven into a cable or some other similar disturbance, the faults in the 9000-volt cable average from two to four per hundred miles per year.

N. S. Diamant: I would just like to touch on the question of sudden short circuits. The authors speak of "the maximum short-circuit current" that will flow into a fault, and they give the curves of Fig. 4 to further illustrate this point. Now, I take that by "maximum short-circuit current", in per cent of the full-load current, the authors wish to refer to the most unfavorable

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condition possible which will take place if the sudden short circuit were to occur near the zero point of the e.m.f. wave. In this case the current will overshoot and reach nearly twice the value it would have if the short circuit were to occur very nearly at the maximum point of the e.m.f. wave. It seems to me—although it is not clearly stated by the authors—that in Fig. 4 they have given us the most favorable condition of a short circuit under the assumption of ideal machines (of 15 per cent reactance each) with no damping effect. This damping may be roughly taken into consideration, if desired, but in any case I think that it is best to refer the curves and the discussion of a short circuit to the worst possible condition. This point should have been made clear by the authors: thus according to my interpretation of the connection of the six alternators under consideration, the rush of current with 5-per cent tie-bus reactance per generator will be anything between 30 and 60 times full load current—rather than 30—under the ideal condition of no damping. Similarly for the other points of the curves.

H. Mouradian (communicated after adjournment): Mr. Roper's contribution appears to be the first published report of a systematic attempt to study the lightning problem experimentally in the field (rather than in the laboratory), where, it seems to the writer, the problem must receive its ultimate solution.

A study in the field, along somewhat similar lines, has been conducted by The Bell Telephone Company of Pennsylvania during the period 1911 to 1916, this study comprising the observation of lightning effects as influenced by various degrees of protection upon the telephone cable plant in the entire state of Pennsylvania, the entire state of Delaware, part of the state of New Jersey, and certain sections of the states of West Virginia and Ohio. This study included the observation of lightning effects as associated with approximately 25,000 cable pairs, fully protected by means of open space cutouts, and, roughly, 500,000 telephone stations.

As Mr. Roper's paper relates to transformer protection, and the data collected by The Bell Telephone Company of Pennsylvania relates to cable protection, this discussion will only consider some of the broad points involved in the field observation of lightning effects.

As noted by Mr. Roper, "the variations of the lightning itself overshadow the rest of the variables." This is borne out by our experience. In the western half of the state of Pennsylvania, the number of substation arrester operations varied from a maximum of 11,594 operations in 1912 to a minimum of 2962 operations in 1915, a variation in lightning activity of approximately 400 per cent, no change whatever having been made in the type of substation arresters in the meantime.

In reference to the extreme irregularity in the distribution of lightning effects, it appears to us, in view of this feature, that only

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through observations covering a large area carried out over a considerable number of years, will it be possible to secure reliable data. Our experience to date has been such that the writer can unqualifiedly endorse Mr. Roper's conclusion 12, to the effect—"Great care should be used in attempting to draw general conclusions from the experience obtained from a few arresters or during a single season, or from a limited area." It seems best to make no changes in the protection practises in a given area, and to carry out the work of observation for possibly five or six years before drawing final conclusions.

In reference to the two other methods of observation indicated in Mr. Roper's paper, first, the study of the trouble caused by lightning in relation to the number of lightning storms, and, second, the study of the relation of fuse troubles to transformer burnouts,—we have found the first mentioned method very unpromising in our work. As regards the second method, our experience with fuse operations, as compared with other lightning troubles, is that the fuse operations appear to bear a closer relation to the intensity of lightning storms than other types of troubles caused by lightning, such as breakdowns in insulation, particularly in telephone work where practically no power current will follow the path of the lightning current.

The writer would like to suggest that Mr. Roper is probably incorrect in his deduction in section IX of his paper, "Increasing the Size of Transformer Primary Fuses," that increasing the size of fuses from five amperes to twenty-five amperes would not materially change the number of fuse operations.

One other point of similarity, which may or may not be accidental, is in reference to the reduction in fuse operations in 1915 as compared with the fuse operations in 1913, shown on Fig. 13 of Mr. Roper's paper. In the state of Pennsylvania, the number of telephone substation fuse operations decreased from 11,546 in 1913 to 4,975 in 1915, the fuse operations being intermediate (6,913) in 1914. There has been no change in our substation protection practises in the same interval of time. It is very possible, therefore that a large part of the reduction in fuses blown (to explain which reduction certain hypotheses have been made by Mr. Roper) may have been simply due to the difference in the character of the 1913 and 1915 lightning seasons. It may be of interest here to note that the telephone substation fuses in use, associated in series with the substations open space cutouts, wired in ahead of these cutouts, viz., towards the line side, are rated as 10-ampere capacity. As pointed out by Mr. Roper the difficulty of reaching accurate conclusions is very great, and the observer has to be continuously on guard not to ascribe to improved practise what may be simply due to absence or difference in character of lightning.

The writer would also like to suggest that Mr. Roper's last conclusion may be considerably in error, and that if Mr. Roper should continue his interesting experimental work, without fur-

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ther changes in the protection conditions of the 4,000-volt transformers, the future may show a very material increase in the ratio of the percentage of transformer burnouts in the class "A" areas to the percentage of transformer burnouts in the class "C" areas.

One detail point seems worth referring to. It appears to the writer that the data presented in Mr. Roper's paper indicates, if the difference in the character of the lightning seasons is not taken into account, that the increase in the ratio of arresters to transformers should be credited with a larger percentage of responsibility than the 20 per cent indicated in Mr. Roper's summary, probably as high as 50 per cent. This thought is suggested by the study of Table VIII and Mr. Roper's own statement, in regard to this same table, that "the percentage of fuses blown in class 'A' is less than one-third of that in class 'C'."

Another thing the study of Mr. Roper's paper suggests, and about which the writer would like to secure Mr. Roper's opinion is whether, considering the question purely from the standpoint of lightning protection, the troubles from blown fuses would not be materially reduced, if the grounds at the substations on the neutral wires were removed.

N. L. Pollard: Replying to Mr. Taylor's question concerning the increase of cable troubles as indicated by the table, will say that the total number of troubles per mile of cable and overhead lines has decreased for the 60-cycle system but has increased slightly for the 25-cycle system. The slight increase on the 25-cycle system is undoubtedly due to the fact that we have not installed on this system the protective apparatus to the extent that we have on the 60-cycle system.

The failures on the 60-cycle cables alone, increased materially in 1915. This, we think, may be due partly to the installation of feeder reactances on both ends of the tie feeders connecting our City Dock, Marion and Essex Stations. Since the installation of these reactances, the nature of the cable breakdowns has changed from a single-phase failure to ground, to a breakdown between phases. The majority of the cable breakdowns has occurred on the tie feeders equipped with these reactances and we are led to believe that the installation of the reactances must have some bearing on the breakdowns.

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THE RELATION OF PURE SCIENCE TO INDUSTRIAL RESEARCH

PRESIDENT'S ADDRESS

BY J. J. CARTY

IT IS not strange that many years ago Huxley, with his remarkable precision of thought and his admirable command of language, should have indicated his dissatisfaction with the terms "pure science" and "applied science", pointing out at the same time that what people call "applied science" is nothing but the application of pure science to particular classes of problems. The terms are still employed, possibly because, after all, they may be the best ones to use, or perhaps our ideas, to which these expressions are supposed to conform, have not yet become sufficiently definite to have called forth the right words.

It is not the purpose of this address, however, to suggest better words or expressions, but rather to direct attention to certain important relations between purely scientific research and industrial scientific research which are not yet sufficiently understood.

Because of the stupendous upheaval of the European war with its startling agencies of destruction—the product of both science and the industries—and because of the deplorable unpreparedness of our own country to defend itself against attack, there has begun a great awakening of our people. By bringing to their minds the brilliant achievements of the membership of this Institute in electric lighting and power and communications and by calling their attention to the manifold achievements of the members of our sister societies in mechanical and mining and civil engineering, and the accomplishments of our fellow-workers, the industrial chemists, they are being aroused to the vital importance of the products of science in the national defense.

Arising out of this agitation comes a growing appreciation of the importance of industrial scientific research, not only as an

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aid to military defense but as an essential part of every industry in time of peace.

Industrial research, conducted in accordance with the principles of science, is no new thing in America. The department which is under my charge, founded nearly forty years ago to develop, with the aid of scientific men, the telephone art, has grown from small beginnings with but a few workers to a great institution employing hundreds of scientists and engineers, and it is generally acknowledged that it is largely owing to the industrial research thus conducted that the telephone achievements and development in America have so greatly exceeded those of other countries.

With the development of electric lighting and electric power and electric traction which came after the invention of the telephone, industrial scientific research laboratories were founded by some of the larger electrical manufacturing concerns and these have attained a world-wide reputation. While vast sums are spent annually upon industrial research in these laboratories, I can say with authority that they return to the industries each year improvements in the art which, taken all together, have a value many times greater than the total cost of their production. Money expended in properly directed industrial research, conducted on scientific principles, is sure to bring to the industries a most generous return.

While many concerns in America now have well organized industrial research laboratories, particularly those engaged in metallurgy and dependent upon chemical processes, the manufacturers of our country as a whole have not yet learned of the benefits of industrial scientific research and how to avail themselves of it.

I consider that it is the high duty of our Institute and of every member composing it, and that a similar duty rests upon all other engineering and scientific bodies in America, to impress upon the manufacturers of the United States the wonderful possibilities of economies in their processes and improvements in their products which are opened up by the discoveries in science. The way to realize these possibilities is through the medium of industrial research conducted in accordance with scientific principles. Once it is made clear to our manufacturers that industrial research pays, they will be sure to call to their aid men of scientific training to investigate their technical problems and to improve their processes. Those who are the first to avail

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themselves of the benefits of industrial research will obtain such a lead over their competitors that we may look forward to the time when the advantages of industrial research will be recognized by all.

Industrial scientific research departments can reach their highest development in those concerns doing the largest amount of business. While instances are not wanting where the large growth of the institution is the direct result of the care which it bestowed upon industrial research at a time when it was but a small concern, nevertheless conditions to-day are such that without cooperation among themselves the small concerns cannot have the full benefits of industrial research, for no one among them is sufficiently strong to maintain the necessary staff and laboratories. Once the vital importance of this subject is appreciated by the small manufacturers many solutions of the problem will promptly appear. One of these is for the manufacturer to take his problem to one of the industrial research laboratories already established for the purpose of serving those who cannot afford a laboratory of their own. Other manufacturers doing the same, the financial encouragement received would enable the laboratories to extend and improve their facilities so that each of the small manufacturers who patronizes them would in course of time have the benefit of an institution similar to those maintained by our largest industrial concerns.

Thus, in accordance with the law of supply and demand, the small manufacturer may obtain the benefits of industrial research in the highest degree and the burden upon each manufacturer would be only in accordance with the use he made of it, and the entire cost of the laboratories would thus be borne by the industries as a whole, where the charge properly belongs. Many other projects are now being considered for the establishment of industrial research laboratories for those concerns which cannot afford laboratories of their own, and in some of these cases the possible relation of these laboratories to our technical and engineering schools is being earnestly studied.

Until the manufacturers themselves are aroused to the necessity of action in the matter of industrial research there is no plan which can be devised that will result in the general establishment of research laboratories for the industries. But once their need is felt and their value appreciated and the demand for research facilities is put forth by the manufacturers themselves, research laboratories will spring up in all our great

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centers of industrial activity. Their number and character and size, and their method of operation and their relation to the technical and engineering schools, and the method of their working with the different industries, are all matters which involve many interesting problems—problems which I am sure will be solved as they present themselves and when their nature has been clearly apprehended.

In the present state of the world's development there is nothing which can do more to advance American industries than the adoption by our manufacturers generally of industrial research conducted on scientific principles. I am sure that if they can be made to appreciate the force of this statement, our manufacturers will rise to the occasion with all that energy and enterprise so characteristic of America.

So much has already been said and so much remains to be said urging upon us the importance of scientific research conducted for the sake of utility and for increasing the convenience and comfort of mankind, that there is danger of losing sight of another form of research which has for its primary object none of these things. I refer to pure scientific research.

In the minds of many there is confusion between industrial scientific research and this purely scientific research, particularly as the industrial research involves the use of advanced scientific methods and calls for the highest degree of scientific attainment. The confusion is worse because the same scientific principles and methods of investigation are frequently employed in each case and even the subject matter under investigation may sometimes be identical.

The misunderstanding arises from considering only the subject matter of the two classes of research. The distinction is to be found not in the subject matter of the research, but in the motive.

The electrical engineer, let us say, finding a new and unexplained difficulty in the working of electric lamps, subjects the phenomenon observed to a process of inquiry employing scientific methods, with a view to removing from the lamps an objectionable characteristic. The pure scientist at the same time investigates in precisely the same manner the same phenomenon, but with the purpose of obtaining an explanation of a physical occurence, the nature of which cannot be explained by known facts. Although these two researches are conducted in exactly the same manner, the one nevertheless comes under the head of

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industrial research and the other belongs to the domain of pure science. In the last analysis the distinction between pure scientific research and industrial scientific research is one of motive. Industrial research is always conducted with the purpose of accomplishing some utilitarian end. Pure scientific research is conducted with a philosophic purpose, for the discovery of truth, and for the advancement of the boundaries of human knowledge.

The investigator in pure science may be likened to the explorer who discovers new continents or islands or hitherto unknown territory. He is continually seeking to extend the boundaries of knowledge.

The investigator in industrial research may be compared to the pioneers who survey the newly discovered territory in the endeavor to locate its mineral resources, determine the extent of its forests, and the location of its arable land, and who in other ways precede the settlers and prepare for their occupation of the new country.

The work of the pure scientists is conducted without any utilitarian motive, for, as Huxley says, "that which stirs their pulses is the love of knowledge and the joy of discovery of the causes of things sung by the old poet—the supreme delight of extending the realm of law and order ever farther towards the unattainable goals of the infinitely great and the infinitely small, between which our little race of life is run." While a single discovery in pure science when considered with reference to any particular branch of industry, may not appear to be of appreciable benefit, yet when interpreted by the industrial scientist, with whom I class the engineer and the industrial chemist, and when adapted to practical uses by them, the contributions of pure science as a whole become of incalculable value to all the industries.

I do not say this because a new incentive is necessary for the pure scientist, for in him there must be some of the divine spark and for him there is no higher motive than the search for the truth itself. But surely this motive must be intensified by the knowledge that when the search is rewarded there is sure to be found, sooner or later, in the truth which has been discovered, the seeds of future great inventions which will increase the comfort and convenience and alleviate the sufferings of mankind.

By all who study the subject, it will be found that while the discoveries of the pure scientist are of the greatest importance to the higher interests of mankind, their practical benefits though certain, are usually indirect, intangible or remote.

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Pure scientific research unlike industrial scientific research can not support itself by direct pecuniary returns from its discoveries.

The practical benefits which may be immediately and directly traced to industrial research, when it is properly conducted, are so great that when their importance is more generally recognized industrial research will not lack the most generous encouragement and support. Indeed, unless industrial research abundantly supports itself it will have failed of its purpose.

But who is to support the researches of the pure scientist, and who is to furnish him with encouragement and assistance to pursue his self-sacrificing and arduous quest for that truth which is certain as time goes on to bring in its train so many blessings to mankind? Who is to furnish the laboratories, the funds for apparatus and for traveling and for foreign study?

Because of the extraordinary practical results which have been attained by scientifically trained men working in the industrial laboratories and because of the limited and narrow conditions under which many scientific investigators have sometimes been compelled to work in universities, it has been suggested that perhaps the theater of scientific research might be shifted trom the university to the great industrial laboratories which have already grown up or to the even greater ones which the future is bound to bring forth. But we can dismiss this suggestion as being unworthy.

Organizations and institutions of many kinds are engaged in pure scientific research and they should receive every encouragement, but the natural home of pure science and of pure scientific research is to be found in the university, from which it cannot pass. It is a high function of the universities to make advances in science, to test new scientific discoveries and to place their stamp of truth upon those which are found to be pure. In this way only can they determine what shall be taught as scientific truth to those who, relying upon their authority, come to them for knowledge and believe what they teach.

Instead of abdicating in their favor, may not our universities, stimulated by the wonderful achievements of these industrial laboratories, find a way to advance the conduct of their own pure scientific research, the grand responsibility for which rests upon them. This responsibility should now be felt more heavily than ever by our American universities, not only because the tragedy of the great war has caused the destruction of European institutions of learning, but because even a worse thing has

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happened. So great have been the fatalities of the war that the universities of the old world hardly dare to count their dead.

But what can the American universities do, for they, like the pure scientists, are not engaged in a lucrative occupation. Universities are not money-making institutions, and what can be done without money?

There is much that can be done without money. The most important and most fundamental factor in scientific research is the mind of a man suitably endowed by nature. Unless the scientific investigator has the proper genius for his work, no amount of financial assistance, no apparatus or laboratories, however complete, and no foreign travel and study however extensive, will enable such a mind to discover new truths or to inspire others to do so. Judgment and appreciation and insight into character on the part of the responsible university authorities must be applied to the problem, so that when the man with the required mental attributes does appear he may be appreciated as early in his career as possible. This is a very difficult thing to do indeed. Any one can recognize such a man after his great achievements have become known to all the world, but I sometimes think that one who can select early a man who has within him the making of the scientific discoverer must have been himself fired with a little of the divine spark. Such surely was the case with Sir Humphrey Davy, himself a great discoverer, who, realizing the fundamental importance of the man in scientific discovery, once said that Michael Faraday, whose genius he was prompt recognize, constituted his greatest discovery.

I can furnish no formula for the identification of budding genius and I have no ready-made plan to lay before the universities for the advancement of pure scientific research. But as a representative of engineering and industrial research, having testified to the great value of pure scientific research, I venture to suggest that the university authorities themselves might well consider the immense debt which engineering and the industries and transportation and communications and commerce owe to pure science, and to express the hope that the importance of pure scientific research will be more fully appreciated both within the university and without, for then will come—and then only—that sympathetic appreciation and generous financial support so much needed for the advancement of pure scientific research in America.

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While there are many things—and most important things—which the universities can do to aid pure science without the employment of large sums of money, there are nevertheless a great many things required in the conduct of pure scientific research which can be done only with the aid of money. The first of these I think is this:

When a master scientist does appear and has made himself known by his discoveries, then he should be provided with all of the resources and facilities and assistants that he can effectively employ, so that the range of his genius will in no way be restricted for the want of anything which money can provide.

Every reasonable and even generous provision should be made for all workers in pure science, even though their reputations have not yet become great by their discoveries, for it should be remembered that the road to great discoveries is long and discouraging and that for one great achievement in science we must expect numberless failures.

I would not restrict these workers in pure science to our great universities, for I believe that they should be located also at our technical schools, even at those with the most practical aims. In such schools the influence of a discoverer in science would serve as a balance to the practical curriculum and familiarize the student with the high ideals of the pure scientist and with his rigorous methods of investigation. Furthermore, the time has come when our technical schools must supply in largely increasing numbers men thoroughly grounded in the scientific method of investigation for the work of industrial research.

Even the engineering student, who has no thoughts of industrial research, will profit by his association with the work of the pure scientist, for if he expects ever to tread the higher walks of the engineering profession he must be qualified to investigate new problems in engineering and devise methods for their solution and for such work a knowledge of the logical processes of the pure scientist and his rigorous methods of analyzing and weighing evidence in his scrupulous search for the truth will be of the greatest value.

Furthermore, the engineering student should be taught to appreciate the ultimate great practical importance of the results of pure scientific investigation and to realize that pure science furnishes to engineering the raw material, so to speak, which he must work into useful forms. He should be taught that after graduation it will be most helpful to him and even necesary, if

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he is to be a leader, to watch with care the work of the pure scientist and to scrutinize the reports of new scientific discoveries to see what they may contain that can be applied to useful purposes and more particularly to problems of his own which require solution. There are many unsolved problems in applied science, to-day which are insoluble in the present state of our knowledge, but I am sure that in the future, as has so often happened in the past, these problems will find a ready solution in the light of pure scientific discoveries yet to be made. When thus regarded the work of the pure scientist should be followed with most intense interest by all of those engaged in the application of science to industrial purposes. Acquaintance, therefore with the pure scientist, with his methods and results, is of great importance to the student of applied science. I believe that there is need of a better understanding of the relations between the pure scientist and the applied scientist and that this understanding would be greatly helped by a closer association between the pure scientist and the students in the technical schools.

While I have drawn a valid distinction between the work of the two, they nevertheless have much in common. Both are concerned with the truth of things, one to discover new truths and the other to apply these truths to the uses of man. While the object of the engineer is to produce from scientific discoveries useful results, these results are for the benefit of others. They are dedicated to the use of mankind and, as is the case with the pure scientist, they should not be confused with the pecuniary compensation which the engineer himself may receive for his work for this compensation is slight, often infinitesimally so, compared with the great benefits received by others. Like the worker in pure science, the engineer finds inspiration in the desire for achievement and his real reward is found in the knowledge of the benefits which others receive from his work.

There are many other things which might be discussed concerning the conduct of pure scientific research in our universities and technical schools, but enough has been said to make it plain that I believe such work should be greatly extended in all of our American universities and technical institutions. But where are the universities to obtain the money necessary for the carrying out of a grand scheme of scientific research? It should come from those generous and public spirited men and women who desire to dispose of their wealth in a manner well calculated to advance the welfare of mankind, and it should come from the industries themselves, which owe such a heavy debt to science.

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While it cannot be shown that the contribution of any one manufacturer or corporation to a particular purely scientific research will bring any return to the contributor or to others, it is certain that contributions by the manufacturers in general and by the industrial corporations to pure scientific research as a whole will in the long run bring manifold returns through the medium of industrial research conducted in the rich and virgin territory discovered by the scientific explorer.

It was Michael Faraday, one of the greatest of the workers in pure science, who in the last century discovered the principle of the dynamo electric machine. Without a knowledge of this principle discovered by Faraday the whole art of electrical engineering as we know it to-day could not exist and civilization would have been deprived of those inestimable benefits which have resulted from the work of the members of this Institute.

Not only Faraday in England, but Joseph Henry in our own country and scores of other workers in pure science have laid the foundations upon which the electrical engineer has reared such a magnificent structure.

What is true of the electrical art is also true of all of the other arts and applied sciences. They are all based upon fundamental discoveries made by workers in pure science, who were seeking only to discover the laws of nature and extend the realm of human knowledge.

By every means in our power, therefore, let us show our appreciation of pure science and let us forward the work of the pure scientists, for they are the advance guard of civilization. They point the way which we must follow. Let us arouse the people of our country to the wonderful possibilities of scientific discovery and to the responsibility to support it which rests upon them and I am sure that they will respond generously and effectively. Then I am confident that in the future the members of this Instutite, together with their colleagues in all of the other branches of engineering and applied science, as well as the physician and surgeon, by utilizing the discoveries of pure science yet to be made, will develop without number marvelous new agencies for the comfort and convenience of man and for the alleviation of human suffering. These, gentlemen, are some of the considerations which have led me here in my presidential address to urge upon you the importance of a proper understanding of the relations between pure science and industrial research.

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SUPPLY OF SINGLE-PHASE LOADS FROM CENTRAL STATIONS

BY PHILIP TORCHIO

ABSTRACT OF PAPER

American central stations, contrary to European practise, have extensively adopted single-phase distribution from polyphase stations, balancing the loads among the different phases by grouping of the single-phase feeders or the distributing substations. Voltage regulation for lighting circuits has been supplemented by individual regulators. Generators with good single-phase characteristics were sometimes employed. In other cases generators were installed of larger kilovolt-ampere rating than the kilowatt capacity of the steam unit.

Large customers, using electric welding machines, electric furnaces, etc., assist the balancing by dividing their load between the two or three phases.

In cases of railroad companies' generating stations, the single-phase power is furnished from three-phase generators of special design. In cases of purchased power from central stations, different methods of supply may be available.

In connection with the supply of service to the Western portion of the New Haven Railroad electrification by the New York lighting companies, four methods were considered contemplating the supply of power—(1) directly from the 25-cycle system busbars; (2) from a separate section of the 25-cycle system busbars; (3) from a 60-cycle station with frequency changers at the delivery point; (4) from special 25-cycle generators installed in the latter station. On account of the requirement of parallel operation with the railroad power plant, the first method would not give the necessary load control. The second method was dismissed on account of the requirements of balancers and also longer transmission lines than the other methods. The third plan necessitated a large investment in special apparatus and gave poor efficiency of conversion. The fourth method was adopted as it gave complete control of the load and voltage, and maximum efficiency of transmission. The larger original investment in new generator capacity was partly compensated for by its value to the companies as a standard equipment for supplying their future demands and other three-phase existing loads in the immediate districts. The equipment is described.

CONTRARY to European practise, the distribution of single-phase currents from polyphase stations is very common in American central station practise. The balancing of loads among different phases has been accomplished by grouping of single-phase feeders on different phases. The exacting require-

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ments of regulation for lighting circuits have been met by supplementing the regulation obtained from the main supply with individual regulators on each single phase feeder circuit. These circuits feed different districts.

Where the distribution is done from different substations, fed from a generating station, the transmitting lines between generating station and substations may be two- or three-phase, one of the phases carrying the heavy lighting load in addition to its share of the power load, which is equally divided among the phases. In such cases the substations are divided into two or three groups, each group having the heavily loaded phase connected to a different phase of the generating station, so that the loads of all phases are approximately equally divided.

The operation of such systems has never given any inconvenience. In the early years the distributing stations and the individual customers' loads were small, so that there were not presented great difficulties in balancing the load among different groups of feeders connected to different phases. With the growth of the system and the introduction of distributing substations, fed from a generating station, the unbalancing of phases became a problem, because it was not possible to maintain always balanced loads on different phases, notwithstanding the care taken in the grouping of different substations. In such cases generators were secured with suitable field windings and additional copper in the armature to give good single-phase characteristics; in other cases the generators were also built of greater kilovolt-ampere rating than the kilowatt capacity of the steam unit.

As an illustration of the former case, we may cite the 14,000-kw. three-phase, 10,000-kw., single-phase, 60-cycle generator installed in 1906 in the Waterside station of the New York Edison Company. As illustrations of the second case are the three 19,000-kv-a., 60-cycle generators driven by 15,000-kw. turbo units installed in 1913 in the 201st Street station of the United Electric Light & Power Company of New York. In this case the fields of the generators were also provided with damper windings which would permit them to carry 7500 kv-a., single-phase load. With this precaution taken, the station output is not handicapped by low power factor or unbalanced loads, and is capable of taking on a comparatively large single-phase customer without handicapping the generating capacity.

Usually the load unbalancings are only temporary and of

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relatively high power factor and, therefore, they do not present the same difficulties as when large single-phase loads, often of fluctuating character, are to be supplied. In such cases the customer can greatly assist the central station by dividing his load as nearly as possible between the two or three phases, as it will give a better balanced voltage condition. This is especially true in electric welding, electric furnaces and possibly in single-phase railroad supply. This division of load has been accomplished to good advantage in cases of large industrial installations.

When large amounts of single-phase railway load supply are to be furnished, the railroads have, from the beginning, established the practise of installing three-phase generators to furnish the bulk of the power single-phase, direct from the generators. The generators are of special design. In cases of purchased power from central stations, it may be possible to do away with the special design generators and supply the single-phase loads from the main buses of the power company, if of sufficient capacity, or with the aid of phase balancers or possibly by sectionalizing, on different phases, the railway load.

A very careful study of the most advantageous method of supplying a large single-phase railroad load was made in connection with the negotiations of the New York lighting companies for supplying the New York, New Haven & Hartford Railroad Company with the power for its western end. The conditions of service required the supply of a minimum guaranteed maximum (hourly) load of single-phase power of 6500 kw., at 70 per cent power factor, with momentary peaks of 250 per cent of this load. The supply was to be paralleled with the 35,510-kv-a., single-phase generating station of the New York, New Haven & Hartford Railroad Company at Cos Cob. Conditions for parallel operation were rendered favorable by the existence of two three-phase 11,000-volt lines over which a maximum synchronizing power of 10,500 kw. could be supplied to the lagging station, with approximately 23,500-kw. of power supplied from the leading station.

The supply was to be 25-cycle and capable of controlling its load to maintain a load factor as desired. In addition, the control was to be such as to divide the peak loads with the Cos Cob power station in proportion to the maximum one hour load taken from the respective sources.

The power was to be supplied at the West Farms Junction

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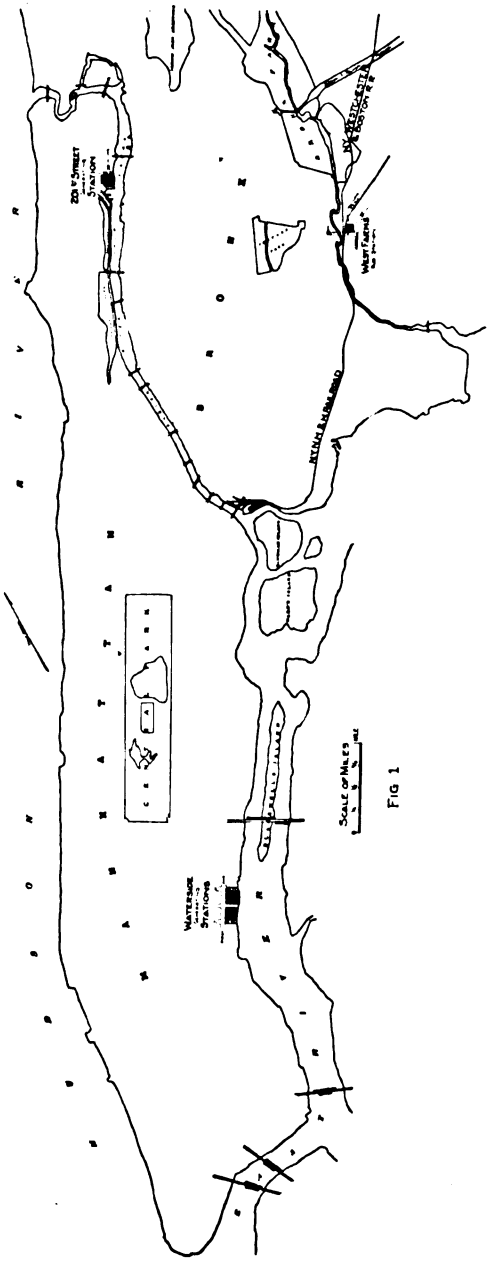

FIG 1

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of the New York, New Haven & Hartford Railroad Company at 22,000 volts, single-phase, with the neutral grounded to the rails, and 11,000 volts, three-phase, for the synchronizing ties. The voltage was to be maintained at this supply point within the limits of 10,500 to 11,500 volts under all conditions of load. The generating capacity that was available for supplying this load at the time of these negotiations was 237,000 kw., 25 cycles, and 22,500 kw. 60 cycles, at the Waterside stations No. 1 and No. 2, located at 40th Street and East River, and 45,000 kw. 60 cycles at the 201st Street station, located at the Harlem River.

The accompanying map, Fig. 1, shows the relative locations of these stations to the proposed point of supply at West Farms. The distance over available duct routes from Waterside station is 9.5 miles, and from the 201st Station 4.5 miles.

With these stations available, the following methods of supply were considered:

I. Power supplied from the Waterside 25-cycle bus which has a generating capacity of 237,000 k.w. operating in parallel. Here the total capacity of the generators would be capable of absorbing the single-phase power without undue heating of the generators.

II. Power supplied from a section of the Waterside 25-cycle bus. In this case the generating capacity operating on this bus section would be comparatively small and phase balancers would be required to balance the load between the phases as the generators were not constructed for supplying a single-phase load greater than 10 to 15 per cent of the capacity of the machines.

In both propositions I and II, the voltage would be stepped up by means of transformers from 6600 to 24,000 volts in Waterside and transmitted at this voltage over 24,000-volt cables to the West Farms Junction of the New York, New Haven & Hartford Railroad.

III. Power supplied from the 201st Street 60-cycle station transmitted at the bus voltage of 7800 volts, three-phase to the West Farms Junction where it would be converted by means of frequency changers to 11,000 volts, 25 cycles.

IV. Special 25-cycle generators installed in the 201st Street station which would be capable of giving the required single-phase load in addition to supplying other 25-cycle load in this territory. Here the voltage would be stepped up to 24,000 volts and transmitted at this voltage to the West Farms Junction of the New York, New Haven & Hartford Railroad.

On studying these four propositions it was found that the first method would be impracticable as it would not give the necessary speed control for division of loads with the Cos Cob

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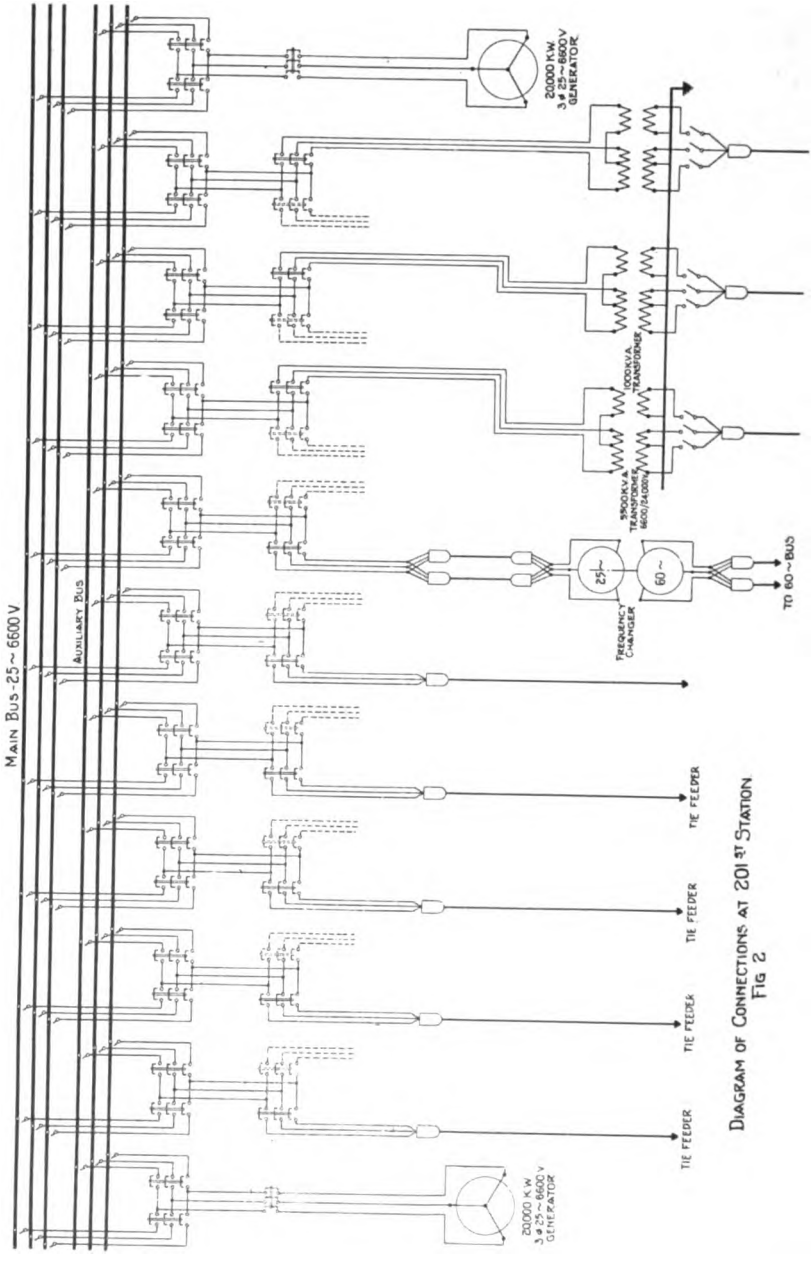

DIAGRAM OF CONNECTIONS AT 201ST STATION
FIG 2

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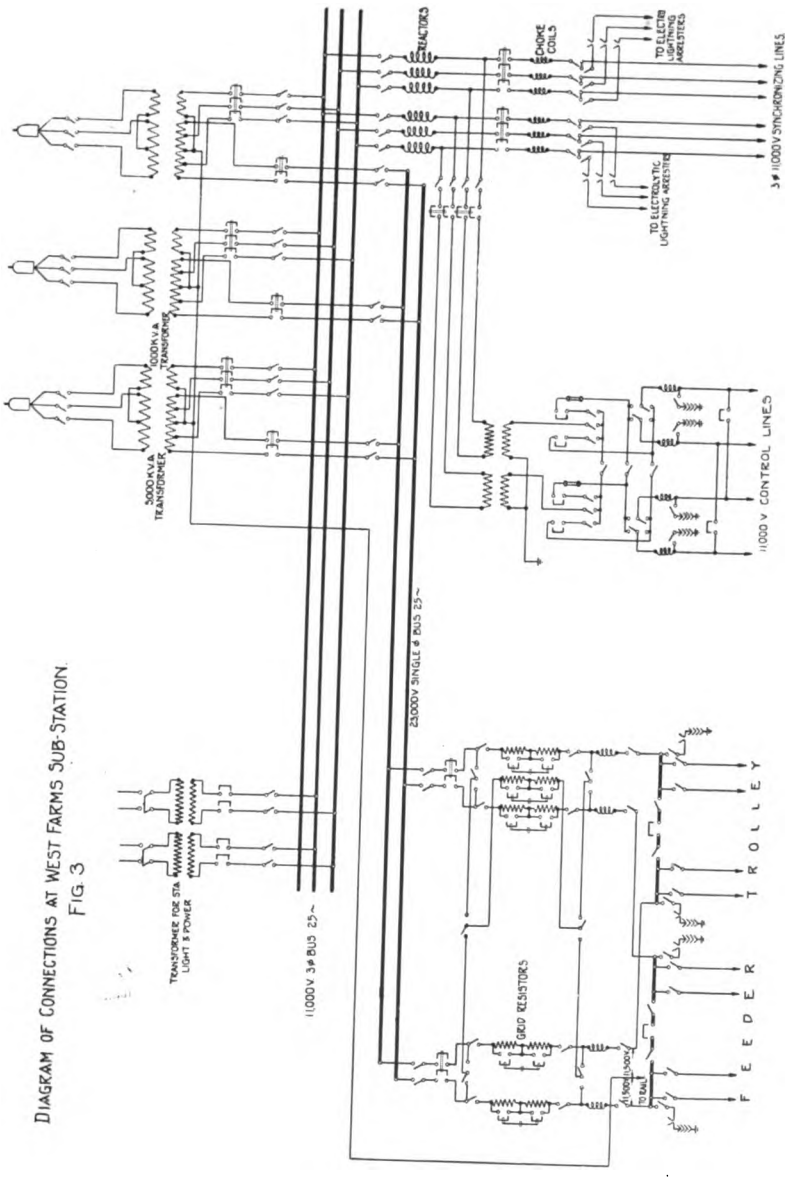

DIAGRAM OF CONNECTIONS AT WEST FARMS SUB-STATION
FIG. 3

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station. It would also not be possible to regulate the voltage supplied without the installation of an expensive regulator for this purpose.

Method II required the installation of phase balancers which was a new type of apparatus and had not been worked out by any manufacturer. The cable lines would be very long and expensive, and there would be no available space in the Waterside stations for installing the transformers and phase balancers.

The layout in method III had the advantages of taking three-phase power from the existing buses and therefore involving the minimum station investment, but the frequency converters would be costly and uneconomical, and limited in application exclusively to this service. In addition they would require an expensive substation for their installation at the West Farms Junction. Also, in order to give the load control, it would be necessary to have the motor of these frequency changers variable speed with certain specific drooping characteristics for dividing the load in the desired proportions with Cos Cob. Regenerative synchronous converter speed control in connection with rotor-wound induction motors was considered for this purpose in order to increase the efficiency of the conversion. This introduced a complicated and rather expensive system of supply.

Method IV seemed to offer the greatest number of advantages as it would give complete control of the load and voltage with a short transmission cable line. While the cost of the new generator capacity required involved a much larger outlay, still it was considered that ultimately such equipment would be utilized both for the railroad load as well as for the company's increasing demands. For this consideration the method proved to be the cheapest when the net results of capital outlay and transmission and transformation losses were considered as part of the cost.

Therefore, when the contract was signed for supplying the New York, New Haven & Hartford Railroad single-phase load, two 25-cycle, 6600-volt, three-phase turbo generators, having a high single-phase rating, were installed in the 201st Street generating station. These generators were rated 20,000 kw., three-phase, at unity power factor, with additional single-phase guarantees of 14,300 kv-a. continuous, after which 17,600 kv-a. can be supplied for seven minutes with a momentary peak of 21,000 kv.-a. for two minutes.

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The heavy single-phase rating of these generators was made possible by the use of special damper windings in the field poles. These windings were necessary in order to neutralize the pulsating armature reaction of single-phase load. The voltage of these generators was made 6600 volts, this being the company's system voltage.

In addition to the supply from these two generators, a frequency changer was connected between the 25- and 60-cycle buses in the 201st Street station. This 25-cycle bus can also transmit or receive power from the Waterside station through four 6000-kv-a. existing tie lines supplying power in the neighboring territory.

The power is stepped up in the 201st Street station to 24,000 volts by three 5500-kv-a., single-phase transformers, with 1000-kv-a. teaser transformers supplying the third leg. This gives a capacity of 11,000 kv-a., single-phase, with one bank and cable out of service, with sufficient three-phase capacity for holding the two generating stations in step during times of trouble on the single-phase lines. All transformers and cables are capable of giving 50 per cent overload for one hour following the full-load run, with a final 100 per cent overload for seven minutes and 150 per cent for one minute.

Figs. 2 and 3 show diagrammatically the method of connections in the 201st Street generating station and the West Farms substation where the connections are made to the New York, New Haven & Hartford Railroad lines.

This supply has now been in operation for fourteen months and has been continuous from the start without any interference or difficulty.

The above description of this supply is made very general as the details have already been published in the technical press.*

**Electrical World*, Vol. 66, No. 24, 1915, Page 1300 and Vol. 66, No. 25, 1915, Page 1365.

Electric Railway Journal, Vol. 46, No. 25, 1915, Page 1200.

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SINGLE-PHASE POWER SERVICE FROM CENTRAL STATIONS

BY R. E. GILMAN AND C. LE G. FORTESCUE

ABSTRACT OF PAPER

The purpose of the paper is to outline several methods by which single-phase power may be supplied from a polyphase system and to discuss their advantages and disadvantages.

The unbalance in voltage when single-phase power is supplied direct from a polyphase circuit is explained. The law of distribution of load in the polyphase system is deduced, and the limitations of this method of supplying single-phase power is discussed.

Single-phase generation is one solution of the problem, motor or steam drive may be used depending on the size of unit required. An outline of the theory of the single-phase generator is given from different points of view.

The essential requirements for phase balancing are deduced from which an outline of the theory of phase balancing is developed. Attention is called to the requirements of the control apparatus. The behavior of the balancer under short circuit is given consideration.

The merits of single-phase generation and phase balancing in the case of a single-phase load from one phase are discussed. with the conclusion that there is little difference in cost between the two schemes and there is much to be said in favor of single-phase generation for such a case.

INTRODUCTION

IT IS the purpose of this paper to outline several methods by which a power company may supply single-phase power, to indicate under what conditions each method may be considered as the most suitable, and to explain, from more than one viewpoint, some of the features of the design and theory of the apparatus required.

Central stations with polyphase equipment are often called upon to supply single-phase loads in small quantities. In general, this is attended with no difficulty, as the individual loads are ordinarily small and a combination of a large number of small loads ordinarily results in a fairly balanced total load. Under certain circumstances, however, even with relatively small single-phase loads, it would be desirable to balance up

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individual feeders if it were possible to obtain the necessary apparatus.

When, however, the individual single-phase loads become relatively large, compared with the total capacity of the station, both the voltage and current unbalance of the system resulting, may cause serious inconvenience and it becomes necessary to provide special means for handling these loads.

It is proposed to consider the problem under the following heads.

1. Single-phase loads supplied direct from the polyphase system.

2. Single-phase loads supplied from separate single-phase generators.

3. Single-phase loads supplied from polyphase system direct, but the balance of the system maintained by means of auxiliary apparatus.

I—Single-Phase Loads Supplied Direct from the Polyphase System

When a single-phase load is supplied direct from any polyphase generator, the effect of this load is to produce an unbalance in the terminal voltage of the machine. The voltage of any phase of a generator when carrying load is the resultant of the induced voltage and the e.m.f. necessary to force the current against the impedance of the phase winding. It is evident, therefore, that if equal currents of the same displacement are supplied by all phases, in other words, balanced load is delivered by the machine, that the terminal voltage diagram is similar to the no-load voltage diagram, but that all e.m.fs. are rotated through the same angle; balanced voltages are therefore maintained. If, however, a single-phase load is applied to the machine (for example in the case of a three-phase generator), the terminal voltages of two legs only are affected by the load current and the resultant triangle of terminal voltages is distorted from an equilateral or balanced triangle. See Figs. 1 and 2.

The division of an unbalanced load between the various machines connected to a polyphase system may be explained as follows: The distortion of the e.m.f. diagram must be the same for all generators connected to common bus bars and for all feeders leaving these bus bars, therefore, the magnitude of the impedance drop in the machines is identical for all units. In other words, the unbalance in load distributes itself between all

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machines connected to the system inversely in proportion to the impedance of the machine plus the impedance of the line circuit up to the point of application of the unbalanced load.

The magnitude of the voltage unbalancing in any system will depend, therefore, upon the relative amount of balanced load as compared with the unbalanced portion. In particular, symmetrical polyphase machinery, such as synchronous motors, synchronous converters or induction motors, will have a pronounced balancing effect on the system independent of the amount of load carried by them.

In addition to the voltage unbalance, single-phase loads on polyphase systems may produce undesirable temperatures in certain portions of the polyphase apparatus unless such apparatus is specially designed to carry unbalanced loads. A full explana-

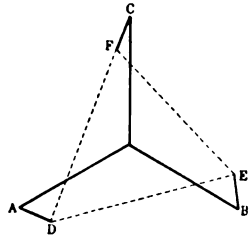

FIG. 1.—CHANGE IN VOLTAGE TRIANGLE DUE TO BALANCED LOAD

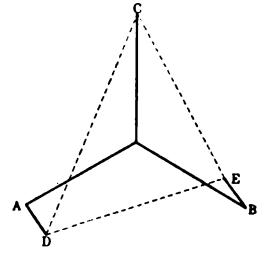

FIG 2.—CHANGE IN VOLTAGE TRIANGLE DUE TO SINGLE-PHASE LOAD

tion of this phenomenon will be given under the discussion on single-phase generators and phase balancing apparatus.

When the unbalance in voltage, or the heating of polyphase machines become excessive to such an extent that the service is in danger, some other means must be considered for supplying the unbalanced loads. The two means, which at once suggest themselves, are the use of separate single-phase generators, or the use of auxiliary apparatus to restore the balance.

In considering these two subjects, two general methods of analysis present themselves. The polyphase generator may be considered as a combination of single-phase generators, or the single-phase generator may be considered as a special case of loading of the polyphase generator. The problem will be presented from both points of view in the following discussion of the action of the single-phase generator and the general problem of phase balancing.

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II—Single-Phase Loads Supplied from Separate Single-Phase Generators

If the single-phase load supplied, is of a different frequency from that of the polyphase system, it is obvious that a single-phase generator is the only logical solution. This generator may be driven either by steam direct, or by a motor connected to the polyphase system. If the frequency of the single-phase load is the same as that of the polyphase system, and it is decided to generate this load as single-phase power, the generators may be driven by motor, if the load is a small percentage of the total station capacity; or they may be steam driven, if the generators are of sufficient output to warrant it. Choice of the drive is largely one of dollars and cents, to be determined by the cost of the plant and the economy of operation. The main advantage in the use of steam drive is that the single-phase load of the station is entirely independent of the main system. The cost of power may be higher for the single-phase plant than for the main system, the difference depending upon the relative size of the units in the two systems, and upon whether steam drive or motor drive be used.

The only piece of apparatus requiring any explanation is the single-phase generator itself. This machine, as ordinarily built, is essentially a three-phase generator, except that the rotor is provided with a damper or a squirrel-cage winding in the faces of the field poles. The general construction and appearance of such dampers is well known, as their use is quite common in connection with different types of synchronous apparatus. In a self-starting synchronous motor, dampers are employed to increase the torque per ampere at starting, and in synchronous converters to prevent phase swinging or hunting from becoming excessive, while in single-phase machines dampers provide a low resistance, a low reactance path for currents induced in the rotor to compensate for the pulsating armature reaction.

The first requisite of any constant-potential machine is that the m.m.f. of the load circuit must not change the main flux of the machine, so long as the load is constant. In single-phase generators, therefore, where the m.m.f. of the load circuit is pulsating, that is, variable in magnitude from one instant to the next, and in position, with respect to the exciting circuit, also from one instant to the next, it is obvious that some other m.m.f. exists of such value at all instants, as to produce, in combination with the load reaction, a m.m.f. of constant value and fixed in

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position with respect to the main poles. This m.m.f. is supplied by currents which are induced in the damper winding.

A complete discussion going into the calculation of these currents is not warranted in this paper, but it may not be out of place to give an illustration of the underlying principle based upon the well known mathematical theorem that two vectors of equal value, rotating in opposite direction at equal angular

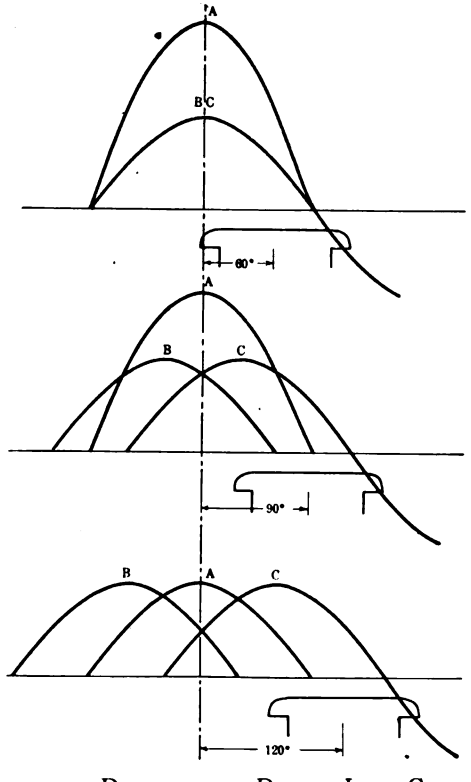

FIG. 3.—A = M.M.F. DISTRIBUTION DUE TO LOAD CURRENT.
B, C = VECTOR COMPONENTS OF A OF OPPOSITE ROTATION.

velocity, produce a sine wave. The diagrams shown in Fig. 3 are drawn under the assumption that the m.m.f. distribution of the armature winding is a sine wave. A little consideration will show that if these damper currents are not of sufficient magnitude to completely neutralize the pulsating component of the armature, the main flux must pulsate at double frequency. Also, that if the resistance to the flow of these currents is high,

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excessive losses may occur in the pole faces of the machine. This latter phenomenon explains the temperature rise which occurs in polyphase machines without dampers when carrying unbalanced loads.

There are some advantages in considering the single-phase generator from the point of view of a polyphase machine having an unbalanced load. It will be necessary, first of all, to accept the following theorem, the mathematical proof of which is given in the appendix and a graphical proof in the portion of this paper devoted to phase balancing.

Any unbalanced polyphase system of currents or e.m.fs. may be resolved into two component balanced polyphase systems, one of which has the same phase rotation as the unbalanced system and the other has opposite phase rotation.

The single-phase load may be considered as an unbalanced three-phase load having the following values.

$$\begin{aligned} I_1 &= 0 \\ I_2 &= I \\ I_3 &= -I \end{aligned}$$

I_1, I_2 and I_3 being the vector values of the line currents of the three-phase system, and I being the vector value of the single-phase load current. This system of currents may be resolved as shown in vector diagram Fig. 9, into two balanced three-phase systems of currents of equal amplitude, one of which has the same phase rotation as the generator and the other has opposite phase rotation.

The three-phase component of normal phase rotation sets up a synchronous rotating m.m.f. in the main winding opposite to the direction of rotation of the main winding relative to the damper winding and which is, therefore, stationary relative to the latter. On the other hand, the counter-phase rotational component sets up a synchronous rotating m.m.f. which has the same direction of rotation as that of the main winding relative to the damper windings, and, therefore, the field set up by it cuts the latter at double synchronous speed, and induces in them double frequency polyphase currents, which produce a rotating counter m.m.f. approximate in value to the m.m.f. set up by the counter phase rotational component of current in the main winding; the degree of approximation being proportionate to the closeness of magnetic coupling between the two windings. If it were possible to make the magnetic coupling perfect, and if the damper resistance were zero, no magnetic flux would be

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set up by the counter-phase rotational component and, therefore, the unbalancing in the terminal e.m.f. would be due only to the $I R$ drop in the main windings.

When the dampers are perfect, the exciting field winding and the pole faces will have no currents induced in them, but since it is not possible to obtain absolute perfection in this respect, a minute amount of double frequency current will be set up in the pole faces and exciting circuit. In machines without dampers such as are commonly used for polyphase systems, these circuits, since they are not symmetrical polyphase circuits, will react on the main windings in an undesirable manner, when the machines are carrying unbalanced loads. For example, a counter-phase rotational m.m.f. induces in the field winding a double-frequency single-phase current, the m.m.f. set up by which in the main field windings, may be resolved into those due to two equivalent balanced three-phase systems of currents, one of which reacts so as to reduce the resultant m.m.f. while the other sets up a rotating m.m.f. of double synchronous speed in the opposite direction to that of the field relative to the main windings. The latter, therefore, induces triple-frequency balanced three-phase currents in the main windings, of the same phase rotation as the fundamental. These currents in turn react on the exciting circuit to set up quadruple-frequency currents, which in turn will react on the main windings to produce three-phase quintuple-frequency currents, and so on. The result is a complete train of three-phase odd harmonics of the same phase rotation as the fundamental and of diminishing amplitude in the e.m.f. of the main winding of the machine. One particular set of these odd harmonics, namely the multiples of three, because they are in three-phase relation in a three-phase system, will produce unequal wave forms on the three phases.

From the foregoing analysis of a single-phase generator, it appears that the single-phase impedance is made up of two elements, namely, the effective impedance of the generator considered as a polyphase machine to the symmetrical three-phase positive rotational component of the load, and its effective impedance to the negative rotational component of the load. The former is the impedance of the machine to a symmetrical polyphase current of positive phase rotation (the positive rotation being assumed to be that of the generator), when the machine is running in the normal direction at synchronous speed *with zero excitation*. The latter is the impedance of the machine to

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a symmetrical polyphase current of negative phase rotation when the machine is running in the normal direction at synchronous speed *with zero excitation*. The former of these quantities is dependent, in some degree, upon the saturation of the magnetic circuit, but corrections can be made from the no-load saturation curves of a machine for any desired degree of approximation. The latter value is only slightly affected by saturation, especially where the damper design is effective.

The single-phase impedance is the sum of the two impedances between neutral point and terminals, obtained in the manner described in the last paragraph, combined as complex quantities.

The effect of the dampers on short circuit is not to increase the transient value, but to sustain it. Therefore, the severity of a short circuit on a machine provided with dampers is not increased, from the magnetic standpoint, but the action continues for a longer period.

It will be obvious from the preceding discussion that the single-phase generator may also be used as a polyphase generator, if so designed, and will be of superior type to the standard polyphase machine, especially where the polyphase load is liable to be unbalanced. When installing single-phase steam-driven generators, the possibility of using them as auxiliaries for the polyphase system may be worthy of consideration. This would be particularly the case if the peaks of the single-phase and polyphase systems occur at different periods.

III—Single-Phase Loads Supplied from Polyphase System Direct, but the Balance of the System Maintained by Means of Auxiliary Apparatus

It has already been shown that any unbalanced single-phase loads will be distributed among the various machines connected to the system in inverse ratio to the impedance of the machine and the circuit up to the point of unbalance. From this consideration it is apparent that if a machine of zero impedance were connected to the system, all of the unbalanced load would be assumed by this unit. Therefore, to produce a balancer, it is only necessary to neutralize the impedance drop due to the unbalanced load. It is possible to produce the equivalent of zero impedance by introducing one or more single-phase boosters supplying a voltage of the proper magnitude and phase position so that the distorted triangle of voltages will be restored to a balanced or equilateral triangle.

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It is evident that if a motor, having balanced symmetrical counter e.m.f., is connected to a balanced three-phase system it will absorb balanced load from the system. If all unbalanced loads were isolated and carried by one generator, it is obvious, as explained before, that the voltage of this generator would become unbalanced. For example, see Fig. 4. The problem now is how to connect this unit to the balanced system, without permitting any of the unbalanced load to be carried from the main generator. It is evident that by adjusting the excitation of this generator, so that the terminal e.m.f. of any phase, for example $A\ B$, is equal to that of the polyphase system, and if, in series with the terminal C a single-phase booster be connected giving an e.m.f. equal to $C\ D$ and of the direction shown in the

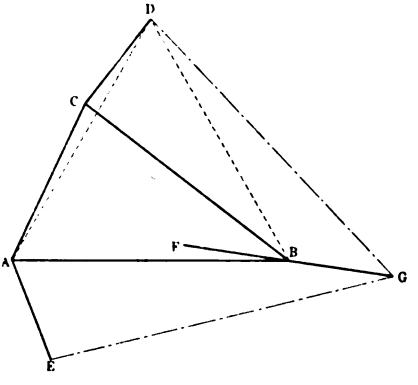

FIG. 4.

figure, a balanced voltage triangle can be produced equal to that of the main system and, if this machine be paralleled with the main system, no redistribution of load will occur. If this generator and booster were driven from the same shaft, it would be possible to remove the driving power and the combined unit would act as a motor-generator taking balanced polyphase power from the system and delivering single-phase energy as a generator. A balancer has, therefore, been produced which will function properly so long as the unbalanced load remains fixed in magnitude and phase. If the phase of the single-phase load should change, it is necessary to change the phase of the booster with respect to the balancer and if the magnitude of the load should change it will be necessary to change the amount of booster in proportion. In the diagram shown, the resultant

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single-phase load is carried across terminals AC, and it is readily seen that if the load should be transferred to terminals AB, or BC the booster would have to be shifted in direction 120 deg. and 240 deg. respectively.

It is also possible to start from any other side of the triangle and by constructing equilateral triangles with these sides as a base, two other boosts are obtained, which can also produce the necessary balance.

It is evident, therefore, that in place of any one of these three boosts, such for example as CD, two boosts of equal voltage and 180 deg. phase displacement can be used if these boosters are connected to points A and B of the triangle. See Fig. 5. Or three boosters can be used, one connected to each corner of the original triangle. From Fig. 4, it will be seen that triangles

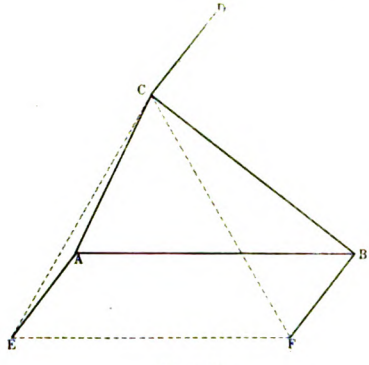

FIG. 5.

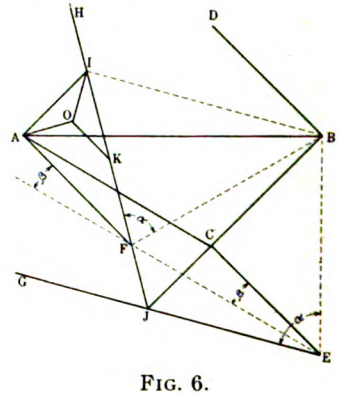

FIG. 6.

CDB and AEB are similar and equal and since by construction the sides CB and EB are 60 deg. apart, the sides CD and AE are 60 deg. apart and the e.m.fs. CD, AE and FB are 120 deg. apart and all equal in magnitude. If any of these values be reversed, it is readily shown that all three boosts can be employed to produce a balanced triangle. It would then be possible to combine all three booster windings on a single armature, which would be wound exactly like a three-phase machine except that the phase displacement of the terminal voltages would be 60 deg. in place of 120 deg. See triangle DEG, Fig. 4.

If starting out with the triangle ABC, an equilateral triangle be constructed with AC as a base, the boost BD can be replaced by two boosts AF and CE, and the equivalent equilateral triangle BEF will be obtained. If from point E a line EG be drawn

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at 30 deg. to the line $C E$, and from point F the line $F H$ be drawn at 30 deg., it is apparent from the figure that with B as an apex a series of equilateral triangles can be formed by measuring equal distances from points E and F respectively along the lines $G E$ and $F H$.

One case, which is of particular interest, is when the two boosts become parallel as shown in Fig. 6. In this case the boosts are at right angles to the line $D B$ and this at once suggests the possibility of replacing them by a balanced three-phase system as indicated by the triangle $A I K$. It has been shown by the construction that triangle $B I J$ is equilateral and it is self evident that if $I O$, $A O$ and $K O$ be combined successively with $I B$, $I J$ and $J B$ that an equilateral triangle would be obtained, as shown

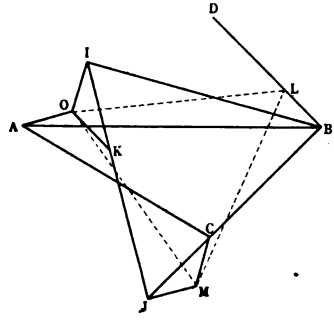

FIG. 7.

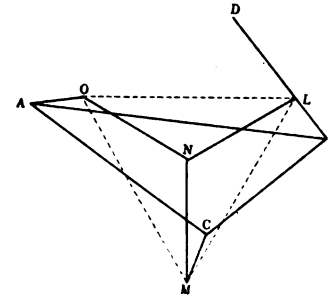

FIG. 8.

by $O L M$, Fig. 7. Also, the construction shows that $A O$, $C M$ and $L B$ drawn from points A, B and C produce the same triangle.

It is to be noted that $A O$, $C M$ and $L B$ are all respectively equal to one-third of the length $B D$. Also that these three boosts form a balanced three-phase system, and combine with $A B$, $B C$ and $C A$ to produce an equilateral triangle with opposite phase rotations.

It has been shown graphically, step by step, how any unbalanced triangle of voltages can be forced to a balanced triangle by various combinations of single-phase boosters using one, two or three boosters to accomplish this purpose. The solution shown in Fig. 7, is the most general for the three-phase system, and can be stated as follows: Any unbalanced triangle of voltages in a three-phase system can be replaced by two balanced systems of the proper magnitude and combined at the correct phase angle. In order to simplify matters, the graphic

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demonstration of this fact has been confined to the case of the three-phase system. It is shown, however, in the appendix to this paper, that the above solution of unbalance is perfectly general.

Given an unbalanced triangle, as shown in Fig. 8, the graphic solution is indicated.

In an extensive polyphase system, it frequently happens that while the aggregate single-phase loads produce fairly balanced polyphase load at the central station bus bars, the voltage at the ends of individual feeders may be considerably unbalanced. It is proved in the appendix that an unbalanced polyphase e.m.f. can be resolved into two balanced polyphase e.m.fs., one of which is of opposite phase rotation to that of the system. If, therefore, at a distributing point, a polyphase booster be connected in series, in the feeder lines, with phases in opposite rotation to that of the system, and if provision be made for changing the phase position and magnitude of the booster e.m.f., the unbalanced e.m.fs. at this point may be boosted into a balanced system. Fig. 10 in the appendix, shows graphically how to obtain the booster e.m.f. required to balance up a distorted system.

Means must be provided to control the voltage and phase angle of the booster according to the balancing requirements. This may be accomplished by two specially arranged regulators, the arrangement of which will depend upon the methods used to adjust phase and voltage in the booster.

Where both current and voltage are seriously unbalanced, the auxiliary apparatus must be such as to supply the elements necessary to produce balance in both voltage and current. It has already been pointed out that when an unbalanced load is supplied from a polyphase system, all the polyphase rotating machinery connected to the system tend to keep the voltages in balance and supply current in such a manner as to approach a condition of balance at the busbars. The particular element of an unbalanced load that must be supplied in order to maintain a balanced load at the busbars, is the counter-phase rotational symmetrical polyphase component of the load.

The impedance of a dynamo electric machine to counter-phase rotational symmetrical polyphase currents may be made extremely low by the addition of carefully designed polyphase dampers or squirrel-cage windings. If, in addition, auxiliary means be provided, externally or internally, to assist the natural

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action of the machine as a balancer, its admittance to the counter-phase rotational currents may be made infinite, so that the terminal e.m.f. of the machine will be absolutely balanced no matter how much counter-rotational current it may be called upon to supply.

The ability of an unassisted dynamo electric machine to act as a balancer is measured by its impedance to the counter-phase rotational component of the unbalanced load. The action of such a machine, when thrown on to an unbalanced system, consists in supplying such an amount of this counter-phase rotational component as will be necessary to pull the system and the machine into the same degree of unbalance. The voltage balance of the system is thereby improved at the expense of the voltage balance of the machine. The voltages that cause unbalance at the machine terminals are the impedance drops due to the counter-phase rotational current supplied by the machine, and are, therefore, counter-phase rotational and symmetrical. One way, therefore, for assisting the machine to maintain a balance, is to supply an equal and opposite counter-phase rotational e.m.f. in series with the windings by means of a booster, and this will render the effective impedance of the machine to these currents zero.

Since with varying degrees and phases of unbalance the impedance e.m.f. will vary in degree and phase position, the external source of e.m.f. must be provided with similar adjustment in voltage and phase position, and the apparatus provided to control these adjustments must respond to the variations of unbalance in the proper degree. The means of adjustment for an auxiliary machine connected rigidly to the main machine may consist of two field windings in quadrature relation, connected to separate exciters. This will permit of adjustment both in magnitude and phase position of the auxiliary machine in respect to the main machine.

The control of the adjustment of the auxiliary machine, with various degrees and phases of unbalancing, is not a simple problem, and until it has been satisfactorily solved, a perfect phase balancer cannot be considered as an accomplished fact. The essential requirements of the regulating apparatus are:

1. That it be extremely sensitive to voltage differences.

2. That it be capable of adjustment so that there will be no hunting between the control elements.

Whether these conditions have been obtained in any installation of balancers, up to the present time, is open to question.

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Since a single-phase e.m.f. may be resolved into two balanced polyphase e.m.fs. of opposite phase rotation, perfect balance may be obtained by one single-phase booster in connection with the main machine. One component of this single-phase voltage must be the counter-phase rotational component required to balance up the terminal voltages of the main machine. The other component, which is of the same phase as the system, is provided for by the excitation of the main machine. The single-phase machine may be arranged so that its middle point is connected to the neutral of all but two of the windings of the main machine, its terminal being connected to the ends of the two remaining windings of the main machine, which would otherwise be connected to the common point, and it should be mounted on the same shaft as the main machine and be provided with means for changing voltage and phase with respect thereto.

The obvious defect of such a system lies in the difficulty of control, since with changing phase of unbalancing, the excitation of the main machine must be changed as well as that of the auxiliary single-phase booster.

A modified form of the same scheme would require a number of single-phase machines of the same phase, connected between the neutral point and each phase of the main machine, the complete set of machines being capable of simultaneous phase shifting, and each machine separately having full voltage control.

As a corollary to the above, it may be stated that any system of unbalanced polyphase e.m.fs. may be used as an auxiliary means of producing perfect phase balancing.

While some of the schemes outlined above may, with restricted phases of unbalancing, offer a satisfactory solution, the use of a polyphase main machine combined with a polyphase auxiliary machine is the simplest solution for the problem of general balancing and all practical balancers will be based upon this feature.

A convenient way of regarding the phase balancer is to consider it as a motor taking power symmetrically from the polyphase system and delivering it to the same system as single phase current. The motor and generator actions tend to counteract one another in any polyphase machine provided with dampers and when the auxiliary booster is added, the annulment is complete after the auxiliary has become adjusted.

The action of a balancer under short circuit condition will, therefore, depend on the range of excitation of the auxiliary. For the initial condition, until the auxiliary has had time to

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adjust itself, the main machine will feed into the short circuit in much the same manner as any other synchronous machine provided with dampers. If the auxiliary had a range sufficient to give complete balance under short circuit, the full polyphase capacity of the system would be concentrated in the short circuit and the phase balancer would necessarily carry a counter-phase rotational load of equal value. In other words, the current delivered by a perfect balancer under short circuit condition, is limited only by the current that the system on which it is operating, can deliver to a symmetrical short circuit.

Practically the short-circuit conditions are not so bad as indicated in the above paragraphs, because the limitation in voltage of the auxiliary machine permits of perfect balancing only up to a certain point. The short circuit stresses in the balancer will nevertheless be much more severe than such as would be obtained in a generator or synchronous condenser of the same size operating on the system.

Conclusion

Where the unbalanced load fluctuates between the different phases and is of sufficient magnitude to cause trouble, a phase balancer is clearly the proper solution of the problem.

When a single-phase load on one phase is to be supplied, the problem becomes one of relative economy and reliability in service of the balancer, as compared with the single-phase generator. The main machine of the balancer set must have the same polyphase output as the alternative single-phase machine, and must also be provided with dampers of equal rating; but it must also be capable of withstanding the more severe short circuit conditions due to its balancing action. In the balancer there is very little torque on the shaft and, therefore, the mechanical design may be cheapened and the operating speed increased. It is doubtful, however, if the main machine of the balancer set can be made much cheaper than a single-phase machine of the same output.

The auxiliary machine will be necessarily costly on account of the double set of poles and the wide range of excitation required. Its exciters must be relatively large in capacity so as to provide rapid change in excitation from full positive to full negative. In addition there will be the control system, which is complicated and costly. It is questionable whether this portion of the balancer set can be made for much less cost than the motor required for the equivalent single-phase machine.

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From an operating standpoint, there is much to be said in favor of single-phase generation. In the first place, it is isolated to a large extent, or, if steam driven, completely, from the main polyphase system. This is of distinct advantage if the single-phase load is subject to frequent and violent interruptions. In the second place, the short-circuit condition resulting from the use of the single-phase machine will be, in general, much less severe and, therefore, less apt to cause trouble and prolonged interruptions in service, than when a balancer is used.

From the point of view of economy of operation, there is little to be said in favor of one over the other; the balance is probably in favor of the phase balancer when compared with the motor generator set, and in favor of the generator when it is steam driven.

APPENDIX

An unbalanced polyphase system can be resolved into two balanced systems of positive and negative phase rotation.

In the mathematical representation of a balanced polyphase system of n phases the symbolic method will be found convenient. In this method each vector is obtained from the preceding one by multiplying it by $e^{j\frac{2\pi}{n}}$ for a positive phase rotational system, and by $e^{-j\frac{2\pi}{n}}$ for a negative phase rotational phase system. In a positive system, therefore, each succeeding vector may be obtained from the first by multiplying it respectively by

$$e^{j\frac{2\pi}{n}} \quad e^{j\frac{4\pi}{n}} \quad e^{j\frac{6\pi}{n}} \quad \ldots\ldots\ldots e^{j\frac{2(n-1)\pi}{n}}$$

These quantities are the imaginary roots of the equation $x^n - 1 = 0$ and may be represented by $a_1, a_2, a_3 \ldots\ldots a_{(n-1)}$, or, instead of these, the equivalent values $a, a^2, a^3 \ldots\ldots a^{(n-1)}$ may be substituted. The equivalent values for negative phase rotation are $a^{-1}, a^{-2}, a^{-3} \ldots\ldots a^{-(n-1)}$. Since these quantities together with unity are the roots of the equation $x^n - 1 = 0$, their sum must be zero, which is one requisite of a balanced polyphase system. In the following discussion all quantities will be either vector quantities or complex quantities all the summations must be considered as vector or complex summations.

Let, $E_1\ E_2, E_3 \ldots\ldots E_n$ and $E_1', E_2', E_3' \ldots\ldots E_n'$ be two

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n phase symmetrical systems of positive and negative phase rotation respectively, so that,

$$\begin{aligned} E_1 &= E_1 & E_1' &= E_1' \\ E_2 &= a\,E_1 & E_2' &= a^{-1}\,E_1' \\ E_3 &= a^2\,E_1 & E_3' &= a^{-2}\,E_1' \\ &\cdots\cdots\cdots & &\cdots\cdots\cdots\cdots \\ &\cdots\cdots\cdots & &\cdots\cdots\cdots\cdots \\ E_n &= a^{n-1}\,E_1 & E_n' &= a^{-(n-1)}\,E_1' \end{aligned}$$

If $V_1, V_2, V_3 \ldots\ldots V_n$ be another system which is unbalanced according to the theorem stated in the opening paragraph it should be possible to obtain values of E_1 and E_1', etc., such that—

$$\begin{aligned} V_1 &= E_1 + E_1' && (1) \\ V_2 &= E_2 + E_2' && (2) \\ V_r &= E_r + E_r' && (r) \\ V_{(r+1)} &= E_{(r+1)} + E'^{(r+1)} && (r+1) \\ V_n &= E_n + E_n' && (n) \end{aligned}$$

Multiply (1), (2) $\ldots\ldots(n)$ by a^n, $a^{(n-1)} \ldots\ldots a^{(n-r+1)} \ldots\ldots\ldots a$ respectively and add. The terms involving E_1 all become $a^n E_1$ and a^n is equal to unity, so that their sum is $n\,E_1$. The sum of the terms involving E_1' is—

$$a^n\,E_1'\,(1 + a^{-2} + a^{-4} + a^{-6} \ldots\ldots\ldots)$$

the quantity in the brackets is zero whether n be odd or even, for if n be odd $a^{-(n+1)}$ is equal to a^{-1} and, therefore, the expression in the brackets may be written—

$$(1 + a^{-1} + a^{-2} + a^{-3} + \ldots\ldots\ldots a^{-(n-1)})$$

the value of which is zero. If n be even and have a value $n = 2m$ the quantity in the brackets is equal to twice the sum of all unit vectors of a symmetrical system of m phases, which comprises the odd members of the n system. The sum of the quantity in the brackets, therefore, is zero whether n be odd or even.

We have, therefore, after following the same procedure with the r^{th} and $(r+1)^{th}$ terms

$$E_1 = \frac{V_1 + a^{-1}\,V_2 + a^{-2}\,V_3 \ldots\ldots a\,V^n}{n}$$

$$E_r = \frac{V_r + a^{-1}\,V_{(r+1)} + a^{-2}\,V_{(r+2)} \ldots\ldots\ldots a\,V_{(r-1)}}{n}$$

$$E_{r+1} = \frac{V_{(r+1)} + a^{-1}\,V_{(r+2)} + a^{-2}\,V_{(r+3)} \ldots\ldots\ldots a\,V_r}{n}$$

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In a similar manner it will be found that

$$E_1' = \frac{V_1 + a' V_2 + a' V_3 \ldots\ldots a^{-1} V_n}{n}$$

$$E_r' = \frac{V_r + a' V_{(r+1)} + a^2 V_{(r+2)} + a^3 V_{(r+3)} + \ldots . a^{-1} V_{(r-1)}}{n}$$

$$E'_{r+1} = \frac{V_{(r+1)} + a' V_{(r+2)} + a^2 V_{(r+3)} \ldots\ldots\ldots a^{-1} V_r}{n}$$

It is clearly seen that

$$E_{r+1} = a E_r$$

and that

$$E'_{r+1} = a^{-1} E_r'$$

and since

$$V_r = E_r + E_r'$$

and

$$V_{r+1} = E_{r+1} + E'_{r+1}$$

the theorem stated in the first paragraph is established.

In a three phase system,

$$E_1 = E_1 \qquad E_1' = E_1'$$
$$E_2 = \omega E_1 \qquad E_2' = \omega^2 E_1'$$
$$E_3 = \omega^2 E_1 \qquad E_3' = \omega E_1'$$

when ω is one of the imaginary cube roots of unity, and if E_a, E_b and E_c be the unbalanced e.m.f. for such that

$$E_a = E_1 + E_1'$$
$$E_b = E_2 + E_2'$$
$$E_c = E_3 + E_3'$$

$$E_1 = \frac{E_a + \omega^2 E_b + E_c}{3}, \qquad E_2 = \frac{E_b + \omega^2 E_c + E_a}{3}$$

$$E_3 = \frac{E_c + \omega^2 E_c + \omega E_b}{3}$$

$$E_1' = \frac{E_a + \omega E_b + \omega^2 E_c}{3}, \quad E_2' = \frac{E_b + \omega E_c + \omega^2 E_a}{3}$$

$$E_3' = \frac{E_c + \omega E_a + \omega^2 E_b}{3}$$

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Applying these to a single phase load on a three phase system, if I_1 be the value of the current.

$$I_a = 0$$
$$I_b = I_0$$
$$I_c = -I_0$$

and, therefore,

$$I_1 = -j\frac{I_0}{3},\ I_2 = \frac{3+j\sqrt{3}}{6}I_0,\ I_3 = -\frac{3-j\sqrt{3}}{6}I_0$$

$$I_1' = +j\frac{I_0}{3},\ I_2' = \frac{3-j\sqrt{3}}{6},\ I_3' = -\frac{3+j\sqrt{3}}{6}I_0$$

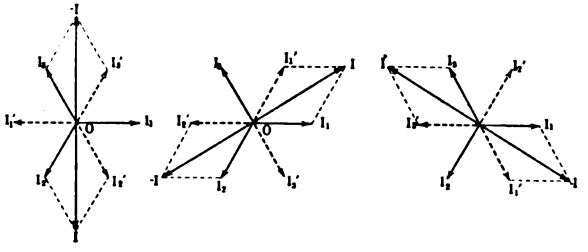

FIG. 9.—SINGLE-PHASE LOAD ON PHASES *A*, *B* AND *C* RESPECTIVELY RESOLVED INTO TWO BALANCED THREE-PHASE COMPONENTS OF POSITIVE AND NEGATIVE PHASE ROTATION.

Fig. 9 shows in a vector diagram the positive and negative phase rotational components of a single-phase load of equal magnitude and power factor on each phase of a three-phase system. The component of the same phase rotation as the system remains constant, while the counter-phase rotational component changes in phase through 120 deg. with each change in load position.

The mathematical results obtained above, may be interpreted as follows:

The negative phase rotational system is the mean of the three symmetrical systems obtained by taking each of the e.m.fs. E_a, E_b and E_c of the original system and considering it as a member of a balanced system. This results in the three systems:

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$$\left.\begin{aligned} E_a &= E_a \\ E_{b1} &= \omega^2 E_a \\ E_c &= \omega E_a \end{aligned}\right\} \quad (1)$$

$$\left.\begin{aligned} E_b &= E_b \\ E_{c2} &= \omega^2 E_b \\ E_{a1} &= \omega E_b \end{aligned}\right\} \quad (2)$$

$$\left.\begin{aligned} E_c &= E_c \\ E_{a2} &= \omega^2 E_c \\ E_{b2} &= \omega E_c \end{aligned}\right\} \quad (3)$$

from which the negative phase rotational component is obtained by taking the mean of the three quantities in the three groups having the same sub-letter.

Similarly the positive phase rotational component is obtained by taking the mean of three symmetrical systems of positive rotation, formed from the elements E_a, E_b and E_c of the unbalanced systems. These are as follows:

$$\left.\begin{aligned} E_a &= E_a \\ E_{b3} &= \omega E_a \\ E_{c3} &= \omega^2 E_a \end{aligned}\right\} \quad (4)$$

$$\left.\begin{aligned} E_b &= E_b \\ E_{c4} &= \omega E_b \\ E_{a3} &= \omega^2 E_b \end{aligned}\right\} \quad (5)$$

$$\left.\begin{aligned} E_c &= E_c \\ E_{a3} &= \omega E_c \\ E_{b4} &= \omega^2 E_c \end{aligned}\right\} \quad (6)$$

Then, as before, each element of the component of positive phase rotation is obtained by taking out of each group the elements having the same sub-letter and finding their mean value.

Fig. 10 illustrates the graphical construction required to carry out the operations indicated above. The triangle A, B and C represents the unbalanced polyphase system which may also be represented by the vectors OA, OB and OC drawn from the centroid O of the triangle A, B and C. Two circles are described with O as center, namely $A\ C_1\ C_3$ having OA as radius, and

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$B\,C_2\,C_4$ having $O\,B$ as radius. In the circle $A\,C_1\,C_3$, $O\,C$ is taken 120 deg. in advance of $O\,A$ and, therefore, corresponds to $O\,C$ in the symmetrical system based on $O\,A$, having negative phase rotation. In the circle $B\,C_2\,C_1$, $O\,C_2$ lags 120 deg. behind $O\,B$ and, therefore, corresponds to the vector $O\,C$ in the symmetrical system of negative phase rotation based on OB. The corresponding vector $O\,3$ of the symmetrical negative phase rotational component is the mean between the vectors $O\,C$, $O\,C_1$ and $O\,C_2$ and is obtained by drawing a line from O to the centroid of the triangle $O\,C_1\,C_3$ that is $O\,3$. By describing a circle with radius $O\,3$ and center O, and taking points *1* and *2* respectively 120 deg.

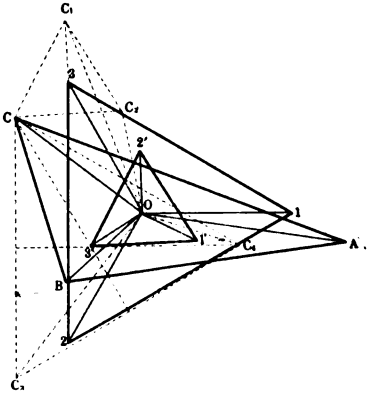

FIG. 10.—UNBALANCED THREE-PHASE SYSTEM RESOLVED GRAPHICALLY INTO TWO BALANCED SYSTEMS OF POSITIVE AND NEGATIVE PHASE ROTATION.

and 240 deg. lagging behind 3, the complete symmetrical negative phase rotational component 1, 2, and 3 is obtained.

The positive phase rotational component is obtained in a similar manner, $O\,C_3$ and $O\,C_4$ having their vectors corresponding to $O\,C$ in symmetrical positive phase rotational systems based on $O\,A$ and $O\,B$ respectively. The vector $O\,3$ of the positive phase rotational system corresponding to $O\,3$ in the negative phase rotational system is the mean of the vector $O\,C$ $O\,C_3$ and $O\,C_4$ and is obtained by drawing a line from O to 3, where 3 is the centroid of the triangle $C\,C_3\,C_4$. The triangle representing the symmetrical positive phase rotational component is obtained by drawing the circles 1 2 3 with O as center and $O\,3$ as radius, the points 1 and 2 being taken respectively 120 deg. and 240 deg. in advance of 3.

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SINGLE-PHASE POWER PRODUCTION

BY E. F. W. ALEXANDERSON AND G. H. HILL

ABSTRACT OF PAPER

The general tendency of the electric power supply industry is toward the centralization of power stations, embracing a variety of loads. In order to be consistent with this development it is highly desirbale that power stations be standardized in essential features, so that they may combine their resources toward the ideal arrangement. The production of single-phase power should not interfere with this general scheme. Looked at from this standpoint, single-phase power can best be produced from polyphase systems. Means are suggested for producing single-phase power without interfering with the broad usefulness of the power station. The mode of operation and theory of phase converters is discussed with particular reference to its adaptability for permitting single-phase power to be derived from polyphase circuits.

IN VIEW of the universal use by power companies of polyphase generation and transmission of electric power for general purposes, the production and delivery of single-phase power must be considered as a special problem.

No power company would or could afford to install a single-phase plant unless its sole purpose was to furnish power to a load that requires single-phase power. In other words, it is settled that polyphase generation and transmission is most efficient, flexible and economical, and the problem presented to power companies when the demand for single-phase power appears is how this may best be produced or derived from their polyphase systems.

Indeed it may be well to extend the problem to cover those cases where such large amounts of single-phase power are required as to apparently justify a special power house and to inquire whether it might not be preferable in such a case to generate and transmit by polyphase and derive the single-phase when and where needed.

Probably the strongest argument for such a view is the practical wisdom in standardizing the electric systems of the country so that they may be tied together as occasion and opportunity

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permit with a minimum of elaborate and power-consuming transforming apparatus. This idea of consolidation and cooperation has recently been given serious attention by many of our ablest men who appreciate the great value of diversified loads and the greater economic efficiency to be obtained by covering the greatest field possible from a common source of electric power supply. It is prudent therefore to condition any conclusion that involves power production with the essential requirement that it be consistent with this general tendency.

The rapid growth of electric power systems makes this a most practical consideration. There are enough differences between electric transmission systems as they now exist without introducing still further complications.

Differences in voltages can not be avoided but to equalize this does not entail great loss of efficiency or undesirable features.

Differences in frequency are more serious and the process of decision upon the most desirable frequency for general use has resulted in adopting a variety of frequencies in different localities. As we now look upon 60 cycles as standard, the use of 50, 40, 30, 25 and possibly other frequencies can not but be regarded as unfortunate since practical considerations will sooner or later force the systems having odd frequencies to seek means to free themselves from the handicap they entail. There are many excellent systems and stations using 25-cycle power and the reasons for adopting 25 cycles were good and sufficient when they were established. Without, therefore, criticising the engineering of these plants, it may be stated that they could be duplicated today with 60-cycle apparatus for less than the original cost and with a distinct gain in general economic usefulness and value.

It seems a logical and highly practical conclusion that general policy should be opposed to the establishment to any considerable extent of power systems having peculiar or special features making them inadaptable to efficient connection with other systems in the vicinity.

Single-phase power may be obtained by:

1. Separate generating and distribution systems designed for single-phase load.

2. Polyphase generation and distribution of single phase load between the phases so that in effect the load becomes a polyphase load.

3. Generation and transmission as polyphase with motor-generator sets at substations.

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4. Mixed single-phase and polyphase load furnished by the same distribution system in combination with methods for correcting the unbalancing effect of the single-phase load.

The first method comes under the head of special and abnormal development already discussed. It has, besides the disadvantages mentioned, the further disadvantage, as regards the generator, of increased size, weight and cost and lower efficiency as compared with polyphase generators. Single- phase generators have been built only for 25 cycles or lower and to a limited extent for special purposes. As compared with other ways of obtaining single-phase power this method seems to offer the least promise of general usefulness.

The second method has the advantage of the polyphase alternator. It is generally used for incandescent lighting distribution and for power and heating where the unit of energy capacity is small and adapted to division between the phases so as to result in very little, if any, unbalancing. It has been proposed and used to a limited extent for heavy single-phase loads, but the difficulty of preserving even an approximate balance between phases makes this method insufficient for large power requirements. It has the further disadvantage of requiring generators of the same frequency as the load demands.

Method No. 3 has the advantage of entire freedom as to generator and transmission and permits a single-phase load of any frequency or power factor to be drawn from any standard polyphase system without disturbing the balance or regulation. It provides means, moreover, of improving the power factor of the system by synchronous motors and from the power system standpoint is the most desirable of all methods when large unit amounts of single phase power is demanded. It is the only method of producing low frequency single phase power from a 60 cycle system. The only objection that is made to this method is the cost of motor-generator sets and the cost of attendance.

The first cost of equipment, it is true, is greater than static transformers alone, but this is balanced to some degree by lower costs at the power station and in the transmission line, and is fully justified in a large power system since it makes it possible to combine the single-phase load with the general load and obtain the benefit of a higher load factor.

The cost of attendance is frequently made negligible by so locating the substations that the attendants may have other

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duties. The expense of attendance in any case is a small percentage of operating costs and can be entirely eliminated by introducing automatic devices to start and switch the motor and generator, such as are coming into successful use for direct-current sychronous converters, waterwheel generators and other rotating apparatus.

This disadvantage, moreover, largely disappears when, as usually happens, a system of single-phase generation is connected to other systems through motor-generator sets for interchange of power.

No. 4 is in general respects the same as No. 2 with the addition of a relatively new development known as the "phase converter" which preserves the balance of the system even when large blocks of single-phase power are taken from the system. Its use greatly extends the possibility of connecting single-phase loads directly to a polyphase system provided the frequency does not have to be changed.

The use of phase converters is relatively recent and perhaps not very well understood. This makes it of interest to discuss the method of balancing and the apparatus employed more in detail.

Theory of Phase Conversion

The earliest known form of phase conversion is splitting the phase by inductance and capacity. In this case the energy of one phase is stored for a fraction of a cycle and released again so as to make the same energy active in another phase. All methods of phase conversion, therefor, involve the storage of energy. Even the phase conversion so called, of wattless currents necessarily involves storage of energy. The expression "wattless energy" is not such a contradiction as it has sometimes been claimed to be. When energy is wattless it means that the energy delivered during one portion of a half cycle is returned during the other portion of the same half cycle; therefore the average energy flow is zero. But at the same time, we must not forget that even if a current is completely wattless, there is a real energy flow in both directions. Thus if we wish to change the phase of the current, whether energy current or wattless current, we must provide means for storing the momentary energy flow for a time corresponding to the change of phase that is to be effected.

The method of storing energy in inductances and condensers is very convenient for high-frequency currents but has not up

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to the present found much practical application for low-frequency power current. There is, therefore, for phase conversion on a large scale, only one type of apparatus that can be considered a rotating machine which stores the energy in the mechanical inertia of the rotor.

In order to arrive at an understanding of the physical functions of phase conversion with a rotating machine, several different points of view are possible, as sometimes one and sometimes another is more helpful in arriving at direct conclusions. The following three methods of looking at the problem may be helpful:

I—Phase Converter Considered as a Motor-Generator

The phase converter is built as a quarter-phase induction motor or synchronous motor with a squirrel cage; one phase is a motor phase and the other phase is a generator phase. The input of the motor phase is equal to the output from the generator phase, not only in the average value of the power flow but in the instantaneous value of energy flow which is delivered and returned during the same half cycle. The only difference between the energy flow in the two phase windings of the converter is that the momentary values of current, volts and energy is delayed $\frac{1}{4}$ cycle in one winding in relation to the other. The squirrel cage is the medium for the transfer of energy, and the mechanical mass of the rotor provides the energy storage. In order to make it possible to store the energy in the rotor, there must be corresponding changes of speed and therefore the rotor must go through a cycle of speed change during each half cycle of the alternating current flow. This speed change of the rotor is evidenced by the vibration which is a characteristic of any single-phase machine. The speed change of the rotor has, however, nothing to do with the electrical functions of the machine in performing as a phase converter. If we could couple the rotor to a flywheel of infinite weight so that the speed change would be zero, the converter would perform in the same way.

Having thus explained how it is conceivable that the phase converter operates as a motor generator, it remains to explain what means are provided for making it perform in this way; in other words, what causes the energy flow in the two phases to vary the same cycle of momentary values although delayed $\frac{1}{4}$ cycle in time. Various means can be provided for producing the desired energy flow and will lead to different types of phase

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converters. Broadly, it can be stated that whatever means are provided, the result of these means must be the desired flow of currents through the windings, and therefore the means must consist in providing the necessary electromotive forces to cause these currents to flow through the windings.

One method of providing these electromotive forces is to use an auxiliary generator which impresses the desired electromotive force on the windings. Instead of a generator any other convenient source of electromotive force may be used, such as a transformer or an induction regulator. Another method is to connect the windings of the converter with reference to the source of power and the load, in such a way that the electromotive forces are furnished automatically by the source of power.

The first method leads to the phase converter connected in shunt to the line and is the type that has been adopted in the phase balancer sets of the Philadelphia Electric Company; for the sake of brevity this type may be referred to as the shunt converter. The function of the shunt converter is to transfer energy from one phase to another in a polyphase system so as to neutralize the effect of single-phase load drawn from the same system in another place. The second method of producing the desired flow of current in the system leads to the series converter. In this type of converter the single-phase circuit is in series with one phase of the converter. The series converter, as applied for changing from single-phase power to polyphase power is described in a paper by one of the authors in 1911. This same arrangement is well adapted for change of polyphase to single phase power and this method is in some cases preferable to the shunt converter. The function of the series converter is not to correct for a single-phase load that has been placed on a polyphase line but to change the single-phase load into a polyphase load before it is connected to the line.

II—The Phase Converter Considered as a Polyphase Generator

This second point of view is more artificial than the first but is more helpful in analyzing the function of the phase converter. For the purpose of such analyzing, a well-known mathematical artifice is made use of. A single-phase current can be considered as resolved into two polyphase components with opposite phase rotation. One of these polyphase components has the same phase rotation as a power system and constitutes

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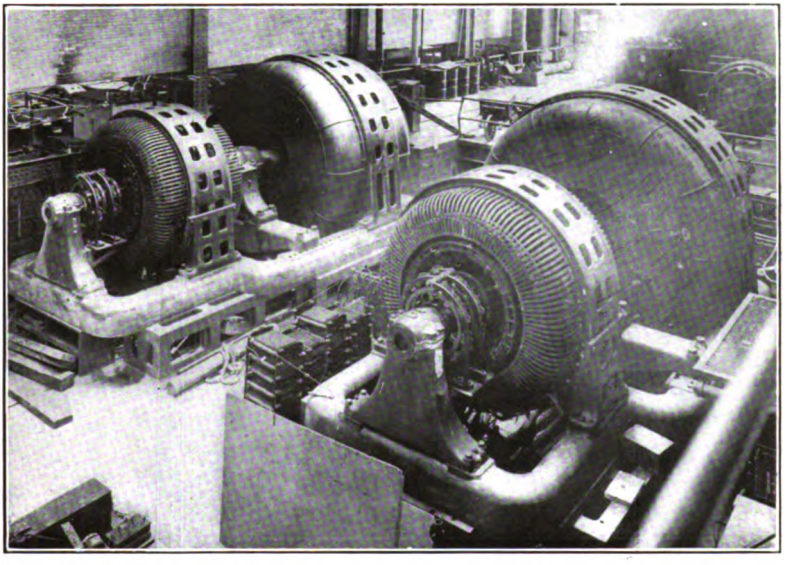

[ALEXANDERSON AND HILL]

FIG. 1—PHASE BALANCER SETS

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a legitimate load on the power system. The other component, which has the opposite phase rotation, is the one that causes the unbalancing of voltage, heating of generators and motors connected to the system, etc. The function of the phase converter is to neutralize this component of the single phase load which has opposite phase rotation. From these considerations, it becomes evident how the phase balancing can be accomplished. This function consists in providing a machine which feeds into the system a polyphase current which has opposite phase rotation to the system, and is equal and opposite to the component of the single phase load we wish to neturalize. It is now evident how the phase balancer ought to be constructed. The converter should be a polyphase machine, not necessarily synchronous, but preferably so in order not to draw lagging current from the system, and means are to be provided for forcing a current to flow through the windings of the phase machine which has opposite phase rotation to the system. The currents of opposite phase rotation are to be regulated in magnitude and phase corresponding to the single-phase load. One convenient way of producing such adjustable polyphase currents is to provide a polyphase generator with its field controlled by suitable regulators. These considerations lead to the design of the shunt converter with direct connected balancer and regulators such as used by the Philadelphia Electric Company. The construction of these phase balancers is illustrated in Fig. 1. The sets consist of a main converter and an auxiliary balancing machine which is controlled by automatic regulators. The main converter is mechanically connected to a generator which is called a balancer. The function of this balancer is to circulate polyphase currents of the desired phase and magnitude in the windings of the converter. This auxiliary generator is small compared to the converter because its output is used only to overcome the losses and inductive drop in the windings of the main converter.

III—The Phase Converter Considered as a Transformer

This point of view is also more artificial than the first one but it is helpful in understanding and analyzing the functions of the series converter. The two stator windings of the phase converter are considered as the primary and secondary of a transformer. The squirrel cage rotor is a medium for transferring the current from the primary to the secondary and

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the characteristics of the phase converter as a transformer differs from the ordinary transformer only by the fact that the time phase of the secondary is $\frac{1}{4}$ cycle from the time phase of the primary. This displacement of time phase is due to the time required for the squirrel cage to rotate through the angle corresponding to the location of the primary and secondary windings of the stator. The function of the series converter is easiest explained in connection with a quarter-phase system, but it is obvious that it can be used in a three-phase system by the use of a Scott transformer connection. The object in the use of the converter is to distribute the single-phase load equally in the two phases of the quarter-phase system. If the problem were to distribute the single-phase load in two circuits of a single-phase system, it is easy to see how this could be done by the use of a series transformer. The single phase load might be put directly in series with one circuit through the intermediate of a series transformer. If this transformer has a ratio of 1:1, the current would be equally distributed on the two circuits at all loads. The two phases of the quarter phase system differ from the two circuits of the single phase system for our present purpose only by the relative time phase. However, if the phase converter may be used as a transformer which changes the time phase of the current between its primary and its secondary to the desired degree, it can be used as a series transformer between the single-phase load circuit and one of the phases of the quarter-phase system in the same way and with the same characteristics as stated above with reference to the ordinary series transformer used to distribute the load on two circuits of the single-phase system. Carrying the analogy between the phase converter and the transformer still further, we can trace the source of the electromotive force required to force equal and opposite currents to flow in the primary and secondary windings. This electromotive force is derived directly from the primary circuit. To cause a current to flow through a winding requires a voltage and this voltage is evidenced by the impedance drop in the winding. From the theory of transformation, we have become in the habit of regarding the impedance of the primary and secondary windings of a transformer as a single impedance, which for the sake of convenience can be said to be located in either the secondary or primary windings. In either case we assume that a certain amount of the primary voltage is used up to overcome the impedance drop of the trans-

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former windings. This impedance drop is evidenced by the voltage drop on the terminals of the secondary winding. The same considerations apply to the use of the converter as a series transformer. The ratio of current transformation is for all practical purposes constant at all loads at which the transformer can be used. The voltage drop on the secondary side is the sum of the impedance drop in the primary and secondary winding. In the case of the phase converter, the impedance drop includes the drop in the squirrel cage which is the transfer medium. However, we are also in the habit of measuring the impedance of the induction motor windings on the primary side and look upon the impedance in the stator and the rotor as concentrated in the stator winding. We therefore find that the impedance of a converter when considered as a transformer is the same as the stationary impedance of the same machine measured as an induction motor at standstill. From this analogue, we have a right to expect the following characteristics of the series converter and these conclusions are in entire agreement with practical measurements. The change of a single-phase load into polyphase load is automatic and results in a *perfect distribution of current in the two phases at all loads*. The voltage delivered to the single-phase circuit has a slight drop with increasing load and has the same characteristics with reference to current and power factor that would be obtained by placing an impedance in series with the single-phase circuit equal to the impedance of the windings of the converter.

Applications of Phase Converter

In regard to efficiency and size, the phase converter can be considered as being in the same class as the synchronous condenser. In fact it has substantially the same structure, the difference being that the squirrel cage which is usually employed in the synchronous condensers to counteract hunting becomes in the phase converter the main rotor winding, while the field winding of the synchronous condenser is reduced to a small winding sufficient to carry no-load excitation. Due to the similarity in structure the same machine can act as a synchronous condenser and phase converter at the same time if the windings are proportioned for this purpose. The fact that the machines can be designed so that they are useful as synchronous condensers and phase converters simultaneously is worth consideration in the application of the methods of phase conversion, as several

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methods of application are possible. In the first place, it is possible to place the phase converters either in the power house or at any desired place of the distribution system. Synchronous condensers may be needed on distribution systems for the sake of counteracting low power factor, and such synchronous condensers can, if desired, be designed so that they can in addition be used as phase balancers, in order to make it possible to draw single-phase load from the same system. If, on the other hand, the main load is synchronous converters with unity or leading power factor it may be more practical to locate the phase balancers in the power stations. The single-phase load is usually of low power factor and the lagging current of the single-phase system may be furnished either to the single-phase distribution system by single-phase synchronous condensers or may be furnished in the power house by polyphase machinery after the whole kilovolt-amperes of the single phase load has been converted to polyphase. In the latter case, the phase converter can be used for power factor correction as well as phase conversion, but in that case it must be large enough to convert the whole single-phase-kilovolt amperes at a low power factor and then furnish polyphase current to correct for this power factor; whereas in the other case where the single-phase power factor is corrected for by synchronous condensers the phase converter needs to convert only the power component of the single-phase load. The choice between these methods of conversion will depend upon local conditions of expediency.

The shunt converter is of particular value in those cases when it is expected that single-phase load may be drawn from different phases of a polyphase system. In such cases unbalancing of the single-phase load will be partly neutralized and it will be necessary to convert only the difference between the single-phase loads. There are, on the other hand, cases where the series phase converter can be used to best advantage. Those are cases when it is desired to convert the single-phase load at the point where it is connected to the polyphase system. The series converter has in that case the advantage of simplicity, as the arrangement is automatic and no auxiliary generator or voltage regulator is needed. In cases where a single electric welding machine or arc furnace is to be fed from a polyphase system, the series converter should be recommended. If such an installation has been made with a series converter in order to insure the lowest first cost and it should be desired to add other furnaces

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to the other phases, the same converter might be used as a shunt converter without any increase of converter capacity but with the addition of suitable regulating devices.

It has been pointed out that a synchronous condenser has a structure suitable for phase conversion. The same is the case with an induction motor or a single-phase turbo-generator, in fact any polyphase machine with a squirrel cage. Such machines are always connected in shunt to the line and would, therefore, be available as shunt converters wherever desired. If, for instance, a power house is built primarily for furnishing single-phase power from single-phase generators but it is desired to furnish a certain amount of polyphase power in addition, the objection arises that the polyphase voltage is unbalanced in proportion to the single-phase load. In such a case it might be expedient to use the squirrel cage of the turbo-generator as a converter medium by adding suitable regulating devices. The interchange of current between the phases is then already determined by the load conditions, but the electromotive forces necessary to cause this interchange of current appear in the unbalancing of the line voltage. This unbalancing of voltages can be treated with the same method of analysis as given in the preceding for the unbalancing of current. The unbalancing electromotive forces are resolved into their components and the correcting electromotive force may be furnished by a generator driven either from the turbine shafts or by a synchronous motor. This generator has the same character and functions as the auxiliary balancing generator in the phase converter set. A power house for mixed single phase and polyphase load equipped in this way can be operated in multiple with other power houses using standard polyphase generators.

The methods that may be employed in order to equip a power system so that it can take on mixed single-phase and polyphase load can be classified in the following groups:

A. The use of standard polyphase generators and phase converters for correcting the unbalanced load. The phase converters may be placed either in the power station or substations and may be

1. shunt converters, or
2. series converters.

B. The use of special generators with squirrel cage windings, adapted for mixed single-phase and polyphase load, and an equipment of automatic apparatus to prevent the unbalancing of voltage that the single-phase load tends to produce.

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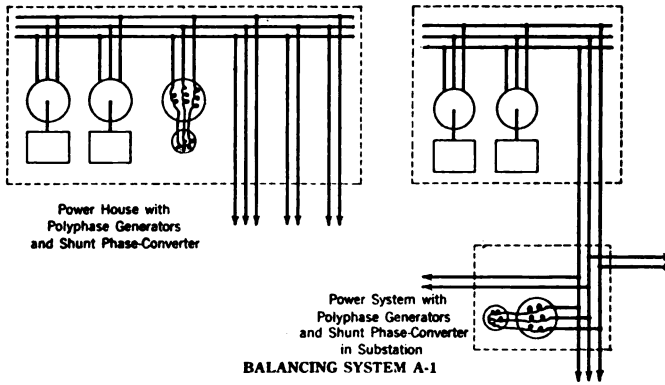
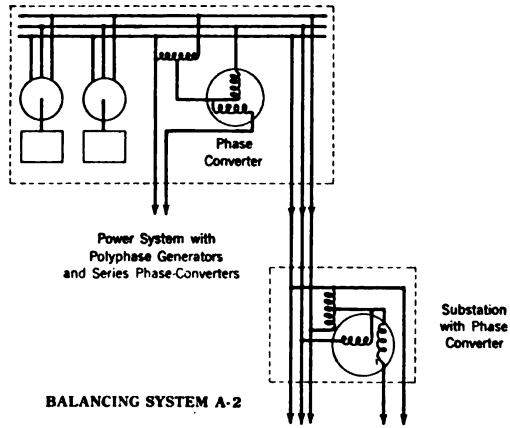
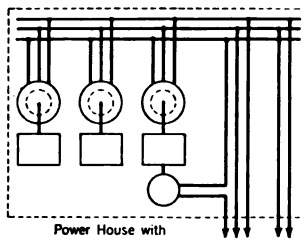


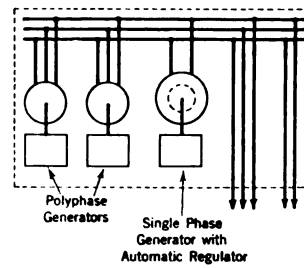
BALANCING SYSTEM A-1



BALANCING SYSTEM A-2



BALANCING SYSTEM B



BALANCING SYSTEM C

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C. The use of standard polyphase generators and special single-phase generators connected to the same bus bars with automatic means for regulating the governors and fields of the single phase generators so that they will absorb the entire unbalancing of the current.

The choice between these three methods of balancing a power system with mixed load will depend upon local conditions and general expedience. All three methods have the advantage of avoiding duplication of the transformation and distribution system. The first method involving the use of the phase converter introduces the least change in standard polyphase power systems and is adapted for the cases where the polyphase load is predominant. The second method is adapted for cases where the single-phase load is predominant, and has the merit of making all of the generating units available for both single and polyphase power as the system may demand. It is thus adaptable to growth and changes in the system, to preservation of good load factor and interconnection with other power systems. The third method does not offer any particular advantages over the two others but is mentioned for the sake of completeness. Its use might be considered in cases where single-phase and polyphase generators are already in use in the same power house and it is desired to use the polyphase distribution system for taking on single-phase load. The efficiency of all three methods may be said as a whole to be on a par. In specific cases some slight advantage may be figured out for each of the systems, but the determining factors will not be so much inherent efficiency of the electrical apparatus as the difference in load factors and the influence of load factors on steam economy.

For the sake of an easy comparison of the different methods proposed, a tabulated set of diagrams are given showing the essential features of each system.

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THE POWER COMPANY'S PROBLEM IN THE ELECTRIC SUPPLY FOR LARGE SINGLE-PHASE LOAD

BY WILLIAM C. L. EGLIN

ABSTRACT OF PAPER

The position taken by the power company is that it should be able to supply all needs of power in the community whether for industrial, street railway or trunk railroad use. The power company must also be able to supply power of uniform pressure whether single-phase, two-phase or three-phase, at whatever voltage best suits the consumer. These conditions are best met by polyphase generating units, and three-phase units are almost universally adopted on account of the economy in transmission which they permit.

When the demand for single-phase current is heavy enough to produce an unbalance, some means of balancing must be provided in order to prevent reduction in the output of the generator, and also to maintain uniform voltage on all phases. Three methods of balancing are discussed; first, by equipping the generator field with damping devices; second, by the use of a separate machine similar to the three-phase induction motor; third, by means of a synchronous phase balancer consisting of a two-unit machine, one of which transfers energy between phases and the other balances the voltage. Correction for power factor on each individual consumer's line is suggested.

FUNDAMENTALLY, the power company should be prepared to supply electric power for all the uses required in the territory which it serves. The greater the variety of utilization of the power company's service, the greater is the diversity factor—the noncoincident demands within a twenty-four hour period or within the yearly period of operation—which increases and improves both the daily and the yearly load factors, and enables the generating plant to operate more efficiently.

In order that it may furnish service in the simplest way, it has been the policy and aim of the power company to select such voltages and frequencies for the generating equipment as would be best adapted to meet the requirements of its consumers' apparatus. It is practically universal in large power companies to have the main generating stations equipped to generate polyphase alternating currents, at high voltages and at frequencies of either 25 cycles or 60 cycles.

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The power companies' principal business in their earlier period was lighting. The use of lighting is usually restricted to the hours of darkness, so that the period of maximum load was a relatively small percentage of each twenty-four hours. The diversity factor of this load, due to the combination of stores, residences and factories, did not improve the load factor very materially, on account of the occurrence simultaneously of these loads between the hours of four and six p.m., forming a very abrupt peak in the load diagrams, especially during the winter months. The value of a motor load was therefore recognized as it would be more continuous and as its requirements for power would increase very considerably over the requirements for lighting.

The next logical step in increasing the load factor was the broad position taken by the power company, to supply all of the needs for power in the community; first, by supplying power to large industries; then to the street railways; and finally, to the steam railways in its territory.

Another important consideration, from the power company's standpoint, is to operate the plant at its maximum efficiency. This means loading the generating units with the load which will produce the maximum steam economy in a steam generating station and the minimum investment in plant.

The generating apparatus must be capable of delivering to the consumers, power of uniform pressure, irrespective of the demands, and the power company must stand ready to supply single-phase, two-phase and three-phase current at any voltage that best suits the individual consumer. These conditions are best met by polyphase generating units; and on account of the economy in transmission, three-phase units are being universally adopted.

The power requirements of individual consumers in a large territory, are of a varied character, demanding a close regulation of pressure through a range of their loads from no-load to full load.

With the balanced three-phase load of a consumer there are no serious difficulties involved, and even with the two-phase load which can be partially balanced by means of T-connected transformers, the difficulties are of little importance, and can be taken care of either by individual automatic regulators on the feeders supplying the consumer, or by regulation of the generating voltage.

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When the demand for single-phase load is heavy, and especially when it produces an unbalance—*i.e.* when a single consumer requires a large amount of single-phase load and it cannot be balanced by other consumers also requiring single-phase load a number of new problems are presented: The capacity of the generating apparatus is materially reduced, on account of the load being limited by the carrying capacity of the windings in the heavily loaded phase, so that the first problem is to provide some means of balancing the single-phase load, or splitting the single-phase load on the generators, to enable the generator to be operated at its normal output. The second problem is to maintain uniform voltage on all phases irrespective of the unbalancing. There are several methods by which this may be partially accomplished:

First, by equipping the field of the generator with damping devices, which consist of copper conductors inbedded in the core and short-circuited at their ends; this enables the transfer of energy from the heavily loaded phase to the under-loaded phase. It, however, cannot be an exact balancing of the load and does not permit of the balancing of potentials. When the unbalance exists only in one phase and is fixed, some adjustments can be made which will approximate uniform voltage upon all three phases. The addition of dampers to the generator, however, reduces its efficiency and adds to its size and necessarily its first cost, and it would probably be necessary to equip all generators in this way. On the other hand, the balancer capacity is added only for the amount of unbalanced single-phase load.

Second, by the use of an external machine connected to the generator, similar in all respects to the three-phase induction motor. By the addition of boosters on each phase, regulation of voltage and also a balance may be affected. When the unbalance exists on one phase and it is known that this will always be the heavily loaded phase, adjustments can be made in the windings of this rotating machine so as to obtain an average of balance of load and an average of balance of voltage.

Third, by means of a synchronous phase balancer, which consists of a two-unit machine, the function of one unit of which is principally to transfer energy between phases; the other unit is a boosting set with two fields at right angles to each other, which balances voltage, thus maintaining constant energy balance and voltage balance. These fields may be controlled by automatic regulators, and a balanced voltage under wide variations from zero to the full range of the blancer set, may

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be obtained. Variations in load may occur on any phase, without in any way affecting its satisfactory operation. The operation of the balancer set does not, in any way, affect the economy of the generator. It does permit the generator to be operated at its most efficient load and to carry a full load, irrespective of the unbalance, up to the capacity of the balancer set. The losses in the synchronous phase balancer and booster are the usual losses in rotating synchronous apparatus, consisting of the losses in the windings and fields, windage and friction of its bearings. The efficiency of a machine of 5000 kw. is approximately 94 per cent.

As previously noted, two single-phase loads may be partially balanced by T-connected transformers, and naturally three or more single-phase loads may be distributed on the three phases in the way to produce the best balancing effect; so that with the increased demands for single-phase load, additional balancer capacity will not be required in a large generating station. On account of this being a synchronous machine, the portion of the unit which is designed to transfer energy, will be made somewhat larger and could be used as a synchronous condenser to improve the power factor of the system.

The principal demand from large consumers is alternating current, either single-phase, two-phase or three-phase, at some determined, practically uniform voltage. With varying demands from no-load to full load, good regulation may be obtained by the various automatic devices to regulate the generating voltage on individual feeders. Variation in voltage upon feeders, however, may become excessive with inductive loads. These loads may also produce at the generating station a low power factor, with a consequent under-loading of the generators, reducing their capacity and possibly necessitating their operation at some point lower than their maximum steam economy.

There are great variations in the power factors of individual consumers, depending upon the nature of their loads. As this also prevents the economical loading of the generating units. some means should be provided to correct the power factor, and I believe that each individual consumer should be corrected for practically unity power factor and the proper synchronous condenser capacity introduced at some point in the consumer's line where the most economical results can be obtained. This, however, will vary very largely with each individual consumer and must be studied in each case.

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DISCUSSION ON "MEGGER AND OTHER TESTS ON SUSPENSION INSULATORS" (HUNT), "EXPERIENCES IN TESTING PORCELAIN INSULATORS" (CREIGHTON), "A NEW METHOD OF GRADING SUSPENSION INSULATORS" (MARVIN), CLEVELAND, OHIO, JUNE 28, 1916. (SEE PROCEEDINGS FOR JUNE, 1916.)

(Subject to final revision for the Transactions.)

F. W. Peek, Jr.: I would like to say a word of warning on the danger of misinterpreting data, especially in regard to insulator testing. I have noticed that there is a great tendency to do this. For instance: The conclusion that a certain specified test is better than another test, and selects the good insulators from the bad, because a greater percentage of insulators are destroyed by that test, may be erroneous. It is, perhaps, best to take a practical example by way of illustration.

It is bad practise to test any insulation up to within a few per cent of the breakdown voltage, as damage always results. The strength of a given thickness of any given kind of insulation *in good condition* will vary from the average 5 to 10 per cent plus or minus on account of structural differences, etc. For instance, the strength of a given thickness of porcelain *in good condition* which averages 100 kv. may vary, for different pieces, from 90 to 110 kv. If this porcelain is arranged in insulators with a flash-over voltage of 100 kv. 60-cycle, and tested at 60 cycles until flash-over takes place, the failure will be about 50 per cent. This follows from the fact that the strength of about 50 per cent of this insulation is below 100 kv. The "high-frequency" flash-over voltage is higher than the 60-cycle flash-over voltage.* Thus, if high frequency is employed so that it is possible to apply a higher voltage, or 105 kv., before arc-over occurs, the percentage failure will be about 75 per cent. In the above test a greater loss will occur on *good* porcelain at high frequency than at 60 cycles. The action is not selective, much porcelain is destroyed, and that porcelain which passes will be damaged and much worse than if the tests were not made at all. The conclusion might be reached here that better insulators are being obtained because a greater number are being broken down. This is far from the actual fact for this particular case. A few bad pieces are being broken down, it is true, but much of the good porcelain is also being destroyed, and all of it is being damaged. This is an extreme case and the peculiar conditions obtain because the puncture voltage is so near the arc-over voltage, and an arc-over voltage test is specified. It is a bad test for this particular design.

Naturally, this does not mean that this insulation should not be tested. It means that it should be tested at a voltage lower than the minimum voltage at which good porcelain of this particular thickness and shape will be damaged or broken down. Fortunately, the condition which exists for the above

* "High-Frequency" Damped Oscillations. See F. W. Peek, Jr., "The Effect of Transient Voltages on Dielectrics," A. I. E. E., August, 1915.

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insulator does not obtain in most insulator tests, as the designs are usually such that the puncture voltages are much higher than the flash-over voltages. This should, in general, be the case, when the high-frequency test becomes useful.

The high-frequency test has very important uses and also limitations. Its most important use is to locate cracks and flaws in insulators. It will not detect moisture as readily as the 60-cycle test.

All of the tests in general use are devised for locating faults after they occur; they are successfully used for this purpose. There is much need of tests for anticipating deterioration at the factory in order to eliminate the great expense of testing and changing insulators after a year or so of service. The so-called deterioration of porcelain is due to two main causes—gradual absorption of moisture by porus porcelain, and gradual cracking due to mechanical stress of poor design, cement, firing, etc. Failures often result only after several years of service. There is no volatge test in use at present that will anticipate in the factory conditions which will later cause failure on the lines by absorption and cracking. Such conditions may be anticipated, not by high voltage, but by absorption tests, and such mechanical tests as expansion and contraction, etc.

E. E. F. Creighton: I am going to agree immediately with Mr. Peek on one point and get it out of the way, and that is that there is no electrical test known today that will eliminate all defective porcelain. Porcelains are porous from about 1 per cent down to perhaps 0.005 of 1 per cent, as far as we have been able to measure. We have not yet connected up the relation between the test and the porosity, but we have this one very useful, practical result, that the test with the high frequency oscillator in the factory, where the porcelains come directly from the furnace, and where the oscillator is specially fitted for the test, eliminates on the average about 8 per cent more porcelains than the 60-cycle test.

The man who wants to use the insulators is interested in getting the very last bad one out. The oscillator does not, apparently, take all the bad ones out. There are some of very small porosity which may or may not develop later on into poor insulators by absorbing moisture from the cement. But, at any rate, we can say that the application of the high frequency from the oscillator is one step better than the 60-cycle test. We hope to find some suitable way before long of eliminating the bad insulators immediately after manufacture.

In regard to the other point, the relation of the 60-cycle test to the high-frequency test, as regards the damage possible to insulators. Taking up the illustration that Mr. Peek gave, of an insulator which is just about to fail on the test voltage. In the case of the 60-cycle test voltage, the flashover takes place in the insulator at about 100 kilovolts, the average is in that neighborhood. If the strength of the insulator is a little bit

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below that, the insulator will fail. If the puncture voltage of the insulator is above, the insulator will probably be damaged by the test. The 60-cycle test will leave a certain number of defective insulators to be accepted and placed on the line, when the puncture voltage is only a small percentage above the flash-over voltage.

Turning to the oscillator test, on that same insulator the oscillator test will subject it to 120 kilovolts or 130 kilovolts, and there, again, there will be some insulators which will be ready to break down at that potential, which will not quite break down in the time of application, and they will go through as defective insulators, but after they have gone through as defective insulators, they still have a factor of 30 per cent above their flash-over value, and therefore, from the operating man's standpoint, they are a better insulator than those which barely pass the flash-over test at 60 cycles.

I think that is the answer to the criticism of applying voltages which might damage the insulators. The solution of the problem is to make the insulator so perfect that it will have the proper design and will be made of the proper porcelain to have a factor of safety over, say, the 130 kilovolts of applied potential.

As a result of a comparison between the two tests, the 60-cycle and the high-frequency test, in our factory we have given up entirely the 60-cycle test and replaced it with the high-frequency test. Some of the more recent results, especially those obtained by Mr. Hunt, may make it expedient to apply both the 60-cycle and the high-frequency test to the finished insulators.

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DISCUSSION ON "ELECTRIC DRIVE FOR REVERSING ROLLING MILLS" (WILFRED SYKES AND DAVID HALL), CLEVELAND, OHIO, JUNE 27, 1916. (SEE PROCEEDINGS FOR JUNE, 1916.)

(Subject to final revision for the Transactions.)

K. A. Pauly: There are several points in connection with this paper by Messrs. Sykes and Hall to which I wish to refer in discussion. One of the first points which is worthy of attention is that of the rating given these motors: namely, a horse power corresponding to the maximum torque which they will carry without any mention of the time during which they will carry the load. All will agree that a rating on this basis is not only contrary to the recommendations of the A. I. E. E., but is very unsafe for the purchaser on which to base the relative capacities of competitive equipments for any class of service. That the idea of so rating these motors is a new one will become apparent to any one examining the publications of the company with which the authors are connected. The early publications showed, for example, 3000 h.p. as the capacity for the motors of the Steel Company of Canada now rated at 10,000 h.p. On this same basis, any one of the 6000 h.p. motors at the Gary Works of the Illinois Steel Company might be rated at 20,000 h.p.

As to the relative merits of the electrically-driven reversing mill and its steam competitor, it is difficult to discuss a question of this magnitude in generalities, because there are so many factors affecting the problem, which are more or less important, depending upon the special conditions obtaining in individual cases. However, the characteristics of motors are in most of the essential details especially adapted to rolling mill conditions. They permit of the centralization of the steam plant and the generation of power in high speed, highly efficient units. The authors have made the mistake frequently found in comparing estimates of the relative operating costs of steam versus other methods of drive. Why stop with the steam consumption, when one of the greatest savings results from the increased boiler efficiency due to the more uniform demand for steam made possible by the use of the fly-wheel motor-generator set equalizing the load in the electrically-driven mill. Tests would indicate that boiler efficiencies may be raised twenty per cent or more by relieving the boiler of these excessive demands for steam required by reversing engines.

My experience indicates that a comparison on the proper basis including all the items of first cost, chargeable against each method of drive, would show little if anything in general in favor of steam equipment in first cost, and will always show the electrically-driven mill to be lower in operating costs. The speed and torque characteristics of the motors are ideal, there are no tendencies toward excessive speeds when the piece leaves the rolls and the motor is always in a position to exert its maximum effort when the maximum power is required.

The figures and curves of power consumed in rolling given by

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the authors, check within reasonable margin of the experience of the writer.

In considering the requirements of reversing rolling mill motors, it is interesting to note the similarity between the factors affecting their electrical design and those for a mine hoist. Both are required to accelerate rapidly, and to carry very heavy dead loads, during acceleration. In fact, in these respects the requirements of a mine hoist motor are frequently more severe than for the reversing mill motor. The roll motor is required to accelerate but little in addition to its own armature, and usually reversal and acceleration to partial speed are accomplished without any dead load, although the equipment should have sufficient capacity to accelerate rapidly with the piece in the rolls. On the other hand, the hoist motor must accelerate in addition to its armature the drums, ropes, cages and load which may be equivalent to several times the armature, and must always handle full load throughout the acceleration. It is true that the time allowed for accelerating a mine hoist motor is more than that allowed for the reversing mill motor, but the increased time is not proportional to the increased load to be accelerated, so that frequently from the standpoint of peak loads, the requirements for the mine hoist motor are more severe than those for the reversing mill motor.

The shocks to which a reversing mill motor is subjected are, of course, more severe, and very much more so than those to which a mine hoist motor is subjected, but are the same as those to which the ordinary non-reversing steel mill motor is called upon to meet, so that the reversing mill motor becomes essentially a direct-current motor capable of withstanding the peak loads met with in mine hoist service, constructed mechanically to withstand the shock and vibrations incident to rolling with the windings held firmly to prevent injury from the mechanical and electrical shocks.

The all important question is production, and in my experience the steam advocate has made a greater point of the speed of the steam mill as compared with the electric mill than he has on the questions of economy or first cost, although many have claimed these advantages also, and the present electrically-driven mills are referred to by him as being slow due to the time required to accelerate. In this extremely important detail, the characteristics of the reversing rolling mill motor differ from those of the mine hoist motor apart from the effect of the time of reversal on the peak current taken by the motor. It is well known that time is required to build up and discharge a magnetic field: the rate being dependent upon the time-constant of the field winding.

The importance of this is suggested by the author, but apparently in the equipment thus far installed every reasonable means has not been resorted to, to bring about a rapid change of field and resulting rapid acceleration and retardation. The accumulative compound-windings on the motors tend to increase the time of rolling by lowering the rate of acceleration and decreasing the

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time of retardation. This compounding is not necessary to protect the mill any more than it is necessary to protect a non-reversing mill driven by direct-current or alternating-current motor, many of which are driven by motors without this provision or its equivalent. The compounding, of course, relieves the motor and generator from electrical shocks sufficiently to permit the use of slightly smaller equipment, but this saving is made at the expense of output from the mill. In the equipments we are now building for this work, we will not only take advantage of the shorter time required for accelerating and retarding the shunt motor to reduce to a minimum the time required for rolling, but are using in addition a special system of control, which will be described later in a paper. This takes advantage of the actual characteristics of the rise and fall of the magnetic field to produce a maximum rate of acceleration and retardation of the roll motor, thereby obtaining a faster operating reversing mill than any thus far built.

One of the most important details in the construction of a reversing mill equipment is the motor shaft, and in many instances this detail has been rather slighted. It is true that these shafts are protected by breaking spindles, but it must be borne in mind that the breaking of a spindle must in no way endanger the shaft. A moment's consideration will convince anyone that the motor shaft should be at least one-third larger in diameter to even protect it against injury from a strain sufficiently great to break the breaking spindle; even then there will be little or no factor of safety in the shaft, in spite of the difference in material used for shafting and spindles. In addition to this, the shaft is frequently subjected to extremely severe bending moments in the event of the breaking of a spindle on the diagonal. It has been our practise to recommend shafts much stronger than those installed, and I cannot but feel that eventually serious delays are bound to result from unnecessary weaknesses in this feature.

The question of motor voltages is too elementary to warrant discussion, although considerable importance seems to have been attached to it by the authors. Practically all of the reversing mill motors installed, including the first one, have been designed for voltages ranging from 550 to 750 volts, and where more than one motor has been used, they have been connected in series, resulting in a voltage of the combination from 1000 to 1500 volts. Here as in most problems, involving larger powers, it is essential to use as high voltage as is consistent with reliable operation and reasonable first cost, and the writer feels safe in predicting higher voltages for this work when more experience has been gained with high-voltage direct-current units of large capacity.

The question of windings, compensated and commutating, is also ancient history, the equipments for this service always having been provided with these special means for improving commutation.

E. S. Jefferies: The question brought out in Sykes' and Hall's paper regarding engine builders' claims is very interesting, and

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I would like to point out a few results obtained on the Steel Company of Canada's mill referred to in their paper.

This mill has been operating since the early part of 1913 with very good results, and the experience gained brings out some very interesting answers to the five general questions raised by the steam men in favor of steam rather than electric drive. In the tables herewith, are complete costs covering this installation, and operating costs for the three years 1913 to 1915, and an average for the same period.

As the Hamilton Mill purchases power, I cannot give any comment on the relative costs of steam and electrical drive. However, in Table I is given a comparison showing the operating costs, interest on investment, depreciation and miscellaneous charges covering this particular installation. This shows an average total cost for the three years of only 43.1 cents per ton. This figure includes a depreciation charge which considers the installation as valueless at the end of a 20-year period, and a miscellaneous charge which includes all power for lighting, tables, crane, conveyor, pumps, motors, etc., used in this mill. The largest item, power cost, is exact, as it is metered, and the other items are charges made direct with no estimating, the result being that the total is an exact cost without any estimation whatever, in arriving at the results. These are the actual book figures.

TABLE No. 1.

Year	1913	1914	1915	Average or total	Per cent
Operating	9 months	8 months	12 mo.		
Tonnage	119,230	92,622	174,460	386,312	
Kw-hr. per ton	23.9	22.8	21.5	23.4	
Power cost	$.0160	$0.153	$.0144	$0.157	36.40
Repairs and maintenance	0.077	0.009	0.004	0.006	1.40
Miscellaneous supplies	0.004	0.005	0.003	0.004	0.90
Labor in operation	0.014	0.016	0.013	0.014	3.25
Total operating cost	0.185	0.183	0.164	0.181	
Interest on investment ($156,000)	0.078	0.101	0.054	0.73	16.90
Depreciation (20 years)	0.065	0.084	0.045	0.060	13.95
Total operating and fixed costs	0.328	0.368	0.263	0.314	
Miscellaneous	0.126	0.133	0.115	0.117	27.20
Total cost	0.454	0.501	0.378	0.431	100.00

The question of energy saved during reversal is a very interesting subject in connection with a paper of this kind. How many rollers on reversing mills in this country are paid straight time? How many are paid tonnage rates? The answer is that practically every mill is paying tonnage rates, with the result that speed is the sole question in the operators' mind. Furthermore this speed is obtained by using live steam to reverse the engine rapidly. In a motor-driven mill a certain per cent of the stored

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energy in the rotating parts is saved by regeneration, and is stored in the flywheel for future use, regardless of operating conditions. The one great advantage in answer to question 4 of low power consumption with partial load is that the motor-generator set can be disconnected from the line when the mill is idle, thereby entailing no stand-by losses, such as are met with in steam installation.

The time taken for the Hamilton motor to reverse is still ahead of the handling of the metal on the tables, manipulation, screw-down, etc. That is, the motor is waiting on the mill. Since the figures given by Sykes and Hall on this mill were taken, we have developed a new governing relay which has given us considerably more positive protection and allowed more speed and, therefore, capacity. We have obtained a speed of 125 r.p.m. on our long passes which when rolling from sixteen to seventeen elongations, saves considerable time.

The advantage of an electric mill may be summed up as follows:

1. Low cost of power.
2. Low cost for repairs and maintenance.
3. Small time to get under way from complete shut-down to rolling conditions.
4. Speed proportional to displacement of controller lever from off position.
5. Part of rotative energy of mill parts recoverable for useful work.
6. Stand-by losses nil.
7. Simplicity of control.
8. Few delays necessary.
9. Motor does not race when steel leaves rolls.
10. Constant turning moment.
11. Ideal load to add to any generating station.
12. Lends itself to centralization of power.
13. Simplified mill lay-out.
14. Mill breakages less.
15. Small area or ground space needed.

The floor space necessary for the equipment described was 40 feet by 125 feet, which allows ample room between machines and wall and switchboard, no apparatus being cramped in any way. A 40-inch mill could easily be installed in this same area. In case of necessity the flywheel set need not be located in close proximity to the mill motor, so that in adapting a mill under extreme conditions where very little floor space was available, the flywheel set could easily be located some distance away where more area could be obtained. The real estate charges on some mills located in thickly settled communities must be considered, and in comparing this area with the area necessary for boilers, coal handling machinery, steam engines, pumps, etc. the result is good.

After the mill has been down for any reason, the time necessary for the attendants to have the entire equipment ready for

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maximum rolling conditions is less than ten minutes. It is doubtful whether a steam boiler equipment could be gotten under way from absolute standstill to running conditions in less than four hours. The simplicity of the control as compared to the levers, links and auxiliary cylinders necessary for the steam engine is very noticeable. The entire control wiring between pulpit and power house is contained in a one-inch conduit. All parts of the control are entirely accessible, and any part needing repairs can be changed in a very few minutes. Repairs have been exceptionally low, the largest item being the brush renewal. Delays in the last three years due to this equipment exclusive of the development period, have not amounted to twenty-four hours, and this period was taken up at various times more to be doubly sure that the equipment was in good order rather than take any chance.

When the mill is idle, the flywheel set can be disconnected from the line and allowed to rotate, which means that there is absolutely no loss as compared to steam equipment having to keep the boilers under steam, the steam-line condensation, small leaks, etc. When the steel leaves the roll, there is no racing, as would be the case in the steam engine run by the average operator, the motor maintaining uniform speed, corresponding to the displacement of the control lever from off position. Such complete control of the speed of the mill is ideal when steel is entering and leaving the rolls, as there is no change of speed unless the operator so wishes. The motor exerts a constant turning moment in all positions, whereas the steam engine has its maximums and zeros, every revolution. The saving due to the return of the rotative energy of the mill parts to the flywheel gives a means of saving power which is normally lost in steam-driven mills. If 60 per cent of the rotative energy of the mill motor is returned to the flywheel, 60 per cent of this, namely, 36 per cent of the whole, is available again on the mill shaft for active work.

To any plant, whether purchasing power from central station or receiving power from their own power house, the Ilgner system adds an ideal load due to the fact that it is a fairly constant load. If the mill is run to capacity, the power variations will be very slight. The central station load applies in the same way and lends itself, where power is being purchased on a peak basis, to a very low rate. For a large power plant, the increased load does not amount to very much. Taking as an example of this the Hamilton Mill: A 1200-kw. generator capacity would easily take care of the load. Where mills are located at various points in the plant, which, from a steam power point of view is inefficient, the Ilnger system eliminates such inefficiency by centralization.

The exceptionally low cost of power is probably the most striking feature of this system, the figures shown being actual figures in no way having been adjusted for cost-keeping purposes. The simplicity of the mill lay-out is another feature which must be considered.

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D. M. Petty: I have in mind one or two points I think it would be well to consider in comparing electrical and steam reversing mills. One of the most important points is the flexibility of lay-out. Steam engines, in order to reduce condensation losses, must be near the boiler plant, and while it is possible to locate reversing drives at any position that may be necessary, the fact that mills in recent years are being much more frequently laid out with the idea of reducing the distance that the steel has actually to travel from the soaking pit to the finished product, whatever that may be, is of considerable importance.

The commutators of reversing mill motors I think are probably the most important of electrical problems, because with the reversing mill d-c. drive the commutator is naturally the place where most trouble will be experienced, and most trouble has been experienced. This trouble is not only electrical but mechanical in a good many respects. The number of brushes on the commutator is a direct item in the maintenance charges, but the size of the commutator has a great deal to do with the mechanical troubles which may arise.

So far as the speeds of the motor itself are concerned, they are governed very largely by the speed at which it is desired to run the mill, but the speed of the generators attached to the motor-generator set is not so limited, and I think it is pretty safe to say in regard to d-c. steel-mill motors and generators that the lower the speed, within reasonable limits, the more satisfactory the operation and the lower the operating charges.

The speed of reversal has been emphasized. This should be taken into consideration, but I feel sure that electrical engineers will have no trouble meeting the requirements. It is far more important to insure reliability of operation than to obtain rapid reversal. Size of bearings, method of lubrication, size of shaft and holding of field coils and armature coils in place against heavy shocks are points that stand near the head of the list in importance, in order to make a mill drive reliable.

R. Tschentscher: I would like to correct, first, the statement made by Mr. Hall that the first reversing set was put in at Gary. The first reversing set was in operation, in December, 1905, at Chicago. It was a very small set, about 75 h.p., and the next set of a much larger size, was put in at the same place.

I think there is too much stress being laid on the question of the electrical characteristics of these equipments. As the result of my observation and my experience in the last ten years in operating one of these sets, it is my opinion that the designers should lay more emphasis on the physical arrangement, than on the time of reversal; for example, on the stiffness of the shaft, to prevent oscillations, etc., and on the size of the bearings, to put off as far as possible the time when the bearings must be renewed.

When the first set was purchased in this country, the time of reversal was a subject which was given very careful consideration.

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I think that the time of reversal was specified as three seconds. As a matter of fact, there are practically no mills,—there might be one or two sawmills—that can use a reversal of three seconds that is from full speed in one direction to full speed in the other.

Much has been made out of the rapidity of reversal of the steam engine—true, it does reverse very rapidly, but any one who has watched a blooming mill operate will be impressed with the fact that the reversal is fast, but the time consumed from the moment the steel enters the rolls and the rolls grip the piece, and the engine is started up again, is from one to five seconds, and it is a fallacy to put too much stress on the question of the time of reversal when such rapid reversals cannot be used. The piece has to be manipulated, the screw-down operated, etc. The time required for such operations determines the time required for motor reversal.

Any one about to purchase an outfit always has the question of the relative merits of the reversing drive versus the continuous mill, to decide. Efficiencies that may be guaranteed at full load, to me are more or less valueless. What may be called the capacity factor, the average yearly input to the capacity of the outfit, is very low, indeed. I think in continuous mills it will be found that this capacity factor will vary from 15 to 40 per cent and in the reversing mills from 30 to 70 per cent. Figures I have taken show, in a reversing mill operating for twenty-four hours on the basis of the input to the motor of the motor-generator set, divided by the kw. ratio of that motor, that 60 per cent is extremely rare. On that basis, it appears to me that we ought not to spend too much time in attempting to get the last bit of efficiency, but rather get reliability physically, so that when the demands for the mill are increased in times of high pressure and high prices, the outfit will then respond.

H. D. James: I think that we all appreciate that the development of the electrically-driven reversing mill is another opportunity to "do it electrically." We all of us believe in electric power, many of us believe in central station power. The use of the electric rolling mill has enabled us to occupy another field with our motor applications.

We have learned a great deal in the past ten years about this reversing drive, and I want to emphasize Mr. Tschentscher's remarks that the time of reversal is not the main essential. It was my privilege to assist in developing the drive of which Mr. Tschentscher spoke, and I wish to add that, he himself, did a great deal to make that drive a success. We started out with the idea that time was one of the most important points, and we ended with other ideas. The tendency now seems to be towards a little more time, and a little more substantial mechanical construction.

F. G. Liljenroth: Having been very closely connected with the European practise of reversing rolling mills during the past ten years, it is with the greatest interest that I have read the

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above paper. As Messrs. Sykes and Hall point out, there is quite a difference between the practise in Europe and in the United States, the most noticeable differences being as follows:

Reversible Motor

It seems to be the general practise in the United States to divide the motor, especially the larger sizes, into two units on the same shaft, while the European practise, at least as far as the leading electrical manufacturing companies are concerned, is to build the motor as a single unit, even for the very largest capacities. So, for example, there are to be found in Europe several reversible motors of the same size, that is, with the same torque as the Bethlehem steel motors, which are built in single units, and as far as I know, there is at least one single unit motor built which has a maximum torque of 240 meter-ton—1,750,000 ft-lb.

The advantages of using single-unit motors are evident: lower first cost and better efficiency, besides the advantages of having to deal with only one commutator, which part is always the weakest in a direct-current machine. Such a single commutator need not be larger than each of the commutators of a two-unit motor, inasmuch as the voltage which is used is as high as from 1000 to 1500 volts and consequently the current is the same as at 2×600 volts. There seems to be no disadvantage in using a single unit motor instead of two. It is true that on account of the higher operating voltage the potential between the brush edges (or rather the voltage which would appear between the brush edges on account of the armature reaction, if this wasn ot compensated for by the commutating poles) is higher than if the machine were divided into two parts, but by correctly determining the ratio of the tangential width of the brush to the commutator pitch, etc., it is possible to limit said potential at maximum peak load to less than $2\frac{1}{2}$ per cent of the operating potential, that is, at 1200 volts to less than 30 volts which is allowed even according to American practise, as stated by Mr. Lamme in his very excellent A. I. E. E. paper dealing with the Commutation of Direct-Current Machines. There are, of course, just as here in the United States other provisions made in order to completely compensate for the potential between the brush edges under all conditions of load. For example, these motors are always equipped with compensating winding, as well as commutating poles, the winding of the latter being placed as close as possible to the armature in order to reduce the leakage field of the commutating pole to the lowest possible value. Furthermore, the commutating poles are tapered and have the same axial length as the armature. In order to avoid a time lag at rapid load fluctuations between the armature current and the commutating field, it has been found advisable to make the commutating poles of laminated iron. The air gap of these poles is made very large, at least one inch, while that of the main poles

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is usually about 3/16 in. The armature winding is furthermore provided with numerous equalizing connections, at least one for each slot.

With the above design it has been found that the motors will operate absolutely sparkless, even for the highest peak loads and in watching the commutators of several such machines, they have operated so perfectly that it was impossible to determine whether they carried a load or not. This applied even to peak loads where thenon-compensated potential between the brush edges would have been approximately 40 volts. The average voltage between the two commutator bars, that is, the operating voltage divided by the number of commutator bars between two brush positions does not, for such machines, exceed 20 volts which must be considered a conservative value.

GENERATORS

It is the general European practise to use two generators of from 500 to 750 volts (usually 600 volts) connected in series and consequently the same practise as in the United States. For the newest installations the speed is, however, considerably higher than was the case some years ago, and which still seems to be maintained in the United States. But this, only refers to the modern installations which were completed shortly before and after the beginning of the war. Sufficient time has elapsed since these motor-generator sets were installed and the results obtained have clearly demonstrated that such speeds are entirely satisfactory and safe, and, as far as Europe is concerned, they have caused a revolution in the design of such machines. The first cost is considerably lower, while the space required is also much lower and the efficiency higher. Comparing such a flywheel motor-generator set with the older designs, one is immediately astonished by its small dimensions. The Bethlehem steel set could have had a speed of at least 514 instead of 375 revolutions, that is, at 60 cycles the induction motor should have had 14 poles.

With the higher speed the motor generator can be built much smaller and this particularly refers to the flywheel. For a certain WR^2 it is evident that the mass of the wheel and consequently also its weight can be the same, independent of what speed is chosen, if only the peripheral speed is maintained constant. In most cases, however, the diameter of the flywheel is limited by shipping facilities to about 4 meters—13 ft. and the peripheral speed by the permissible stresses at maximum runaway speed, this usually being taken as 25 per cent above normal speed. The stresses should in no part in the wheel at its runaway speed be permitted to exceed 10kg. per sq. mm. or about 14,000 lb. per sq. in. which values at normal speed would correspond to about 9000 lb. These values are, as seen, very low and conservative, and it is not necessary to use any especially expensive material in the wheel, but only ordinary

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cast steel with an elasticity of 40,000 and an ultimate strength of approximately 70,000. Regardless of these low stresses, it is possible, by using a suitable design of flywheel, to go to a peripheral speed of as high as 430 feet per second and still not exceed a stress of 14,000 lb. per sq. in. at runaway speed. From the above it follows that the lowest speed which should ever be used for such a flywheel should be:

$$\frac{430 \times 0.8 \times 60}{13 \times \pi} = 500 \text{ rev. per. min.}$$

The largest generator which can be built at this speed has a maximum load, that is, peak load, of about 4300 kw., this being under the assumption that the peripheral speed of the armature is not to exceed 150 feet per second and the average voltage between the two commutator bars not to exceed 20 volts and that at peak load, amperes × armature conductors per cm. circumference is about 800.

The Bethlehem motor requires approximately 8500 kw. and it follows, therefore, that its motor generator could readily have been built for 500 revolutions with two series connected generators each for 600 volts. The weight of the flywheel could have been reduced in proportion $\left(\frac{375}{500}\right)^2$ or to approximately one-half and the flywheel effect would still have been retained. This is under assumption, that the diameter of the Bethlehem flywheel is about 13 feet. It is possible, however, that there are other reasons for using the low speed and it would be interesting to obtain information in regard to:

1. The largest permissible diameter of the flywheel limited by transportation facilities.
2. The percentage of runaway speeds which are usually specified.
3. The corresponding permissible stresses in the flywheel as well as the properties and the material which is used.
4. The corresponding peripheral speed whose relation to the stresses is dependent on the design of the flywheel.

Excitation

As far as the excitation is concerned, the European practise comprises what is known as the "indirect" regulation, that is, the rheostats or controllers are not inserted in the generator or motor fields, but in the fields of the exciters. The exciters are used, one for the generators and one for the motor, the voltage of the exciters being regulated. The exciters are, therefore, in turn magnetized from a third exciter which consequently can be very small, working normally as a shunt generator with constant potential. These three machines are driven by a common small induction motor.

The advantages of this scheme are: smaller equipment,

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lower first cost and especially greater reliability as far as the rheostats and controllers are concerned, in that the currents which have to be handled are only from one to two per cent of what would be the case if the "direct" excitation were used. For rolling mill service it is evident that the control equipments have to withstand very severe service both electrically as well as mechanically on account of the rapid breaking of comparatively large magnetic energies and also due to the fact that they are in almost continuous service. The advantages of smaller equipments which are obtained by the smaller apparatus used with indirect excitation are, therefore, obvious. The excitation will be just as rapid as by the direct method, on account of the fact that the magnetic energy stored in the small exciter fields is negligible compared to the large machines.

The compounding is usually made in the way that the main poles of the generators have an opposing series winding which therefore does not have to be reversed. Against this practise it may be argued that an assisting compound winding on the motor would be better, inasmuch as the torque will be increased by strengthening the field. This, however, is more or less an imaginary advantage, as for machines of this kind the saturation curve at normal speed is so flat that a large increase in the field current creates a very small or almost no strengthening of the field.

Concerning the safety devices and the arrangement of the automatic load regulation, etc., the European practise involves several quite interesting departures from the practise in the United States, but space does not permit of further discussion of this subject.

Brent Wiley: It would be well to consider the blooming mill equipment from the standpoint of the entire mill drive, as practically every steel plant is composed of finishing or semi-finishing mills, as well as blooming mills.

During the last eleven years more than three hundred large motor units, totalling over 500,000 h.p., have been installed to drive the main rolls of steel mills.

The following list gives the electrically-driven reversing blooming mills installed, and on order in the United States and Canada. The majority of the equipments have been purchased during the last few years.

				Installed
—	Blooming	Mill	—Algoma Steel Co. Sault Ste. Marie, Can.	1911
34 in.	"	"	—Steel Co. of Canada, Hamilton, Ont.	1913
34 in.	"	"	—Central Steel Co., Massillon, Ohio.	1914
35 in.	"	"	—Bethlehem Steel Co. Bethlehem, Pa.,	1915
35 in.	"	"	—United Steel Co., Canton, Ohio,	On order.
40 in.	"	"	—Inland Steel Co., Indiana Harbor,	" "
32 in.	"	"	—Inland Steel Co., Indiana Harbor,	" "
40 in.	"	"	—Illinios Steel Co., Gary, Ind.	" "
40 in.	"	"	—National Tube Co., Lorain, Ohio	" "
34 in.	"	"	—Chattanooga Steel Co., Chattanooga	" "
35 in.	"	"	—Mark Mfg. Co., Indiana Harbor,	" "
34 in.	"	"	—Ashland I. & M. Co., Ashland, Ky.	" "
34 in.	"	"	—Keystone Steel & Wire, Peoria, Ill.	" "

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REVERSING MOTOR EQUIPMENTS—FOR OTHER TYPES OF MILLS.

	Installed
30 in. Universal Plate Mill Ill. Steel Co., S Chicago,	1908
Plate Mill —Am. Sheet & T.P. Co., Gary, Ind.	1910
" " — ditto	1910
28 in. Structural Mill—Inland Steel Co., Indiana Harbor,	On Order
27 in. Universal Plate Mill Mark Mfg. Co., Indiana Harbor	"

The principal object of the earlier installations was to utilize cheap power and the incidental advantages possible were not taken into account. Experience has demonstrated that motor drive has many favorable features which are of economic value in not only the every day operation of the mill, but assist most materially in the development of the method of operation.

Motor drive gives the greatest latitude regarding the arrangement and design of mill and of the entire plant. Motors can be designed with either high, intermediate or low speed, and with a wide variation in maximum or pull-out torque. Adjustable speed motors give a wide range of operating speeds, with very economical operation of mill, either for constant torque or constant horse power requirements. The regulation of the alternating-current motor is very close, even under a wide range of load, varying only about two and one-half per cent from light to full load. It is capable of standing heavy overloads frequently for comparatively long periods, without undue strain or deterioration. The ease with which power readings can be made instantaneously and for any desired period is of great value in compiling records to ascertain the effect and value of any change that is inaugurated in the development of the mill design.

The general experience in the operation of a new mill is that the results obtained, after a few years, are radically different from the ideas of the possibilities and expectations of what could be accomplished when the design was first conceived. In the majority of cases it is necessary to make a number of assumptions regarding the possibilities of each particular portion of the mill, including capacity of heating furnaces required, permissible reductions per pass speed of rolling, size and shape of product, most desirable from the standpoint of trade demands. The mill is developed as more information is obtained regarding these factors, and the incidental advantages of motor drive have played an important part in accomplishing the most satisfactory results in reversing blooming mills, as well as other types of rolling mills, as the general advantages are the same for all types of motor equipment.

First Cost

It is assumed that the plant is designed with motor drive for the blooming mill, finishing mills, and for the auxiliaries.

The average load on the electric power station to drive a reversing blooming mill with maximum peaks of 15,000 to 20,000 h.p. is approximately 3000 to 3500 h.p., with variations of not more than 15 per cent during the active rolling period of the

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mill. The station capacity will be divided approximately 80 per cent for motors of auxiliary machines and finishing mills and 20 per cent for the reversing mill equipment. In other words, it will require a comparatively small increase of power plant to provide for the blooming mill work which is quite a contrast with the requirements in an addition to a boiler plant for steam engine-operated blooming mill.

Furthermore, the addition of a very uniform load assists in equalizing the total plant load, and thereby increases the efficiency of operation.

The use of central station power is also a very material factor in reducing the first cost, and many steel plants are taking advantage of this point as well as of other favorable factors which purchased power affords. At present, there are more than fifty steel plants obtaining part or all of their electric power from central stations, and are using a total of approximatley 425,000,000 kw-hr. per year, which is approximately 18 per cent of the total electric power required per year by the iron and steel industry.

Economy of Operation

There is more economy of operation to be gained by the electrification of the reversing blooming mill than of any other type of mill. In the case of the averaging existing steam engine-driven mill, the steam consumption can be reduced fully fifty per cent by use of motor drive. This comparison is made on the basis of using electric power as furnished by steam turbines at approximately 5000-kw. capacity. Undoubtedly there are many cases where the gain would be even greater than this, but on account of the limited test data available regarding the steam requirements and general analysis of plant conditions, it has been difficult to establish these facts definitely.

H. S. Page: Analysis of the sequence of operations during rolling might serve to bring about closer unanimity of opinion in regard to the permissible time of reversal. The actual reversal occurs during the time the metal is out of the rolls between passes: is from a comparatively low speed in one direction to about the same, or lower speed in the opposite direction, and can easily be accomplished while the metal is being returned to the rolls. After the metal enters the rolls it is of the utmost importance to have a driving motor capable of accelerating the mill to the maximum speed of the pass just as quickly as possible. The retarding action of any device installed for the protection of the motor should be carefully considered; as the function of most of these auxiliary devices is to prevent rapid acceleration and thus limit the output of the mill.

A few comments might be added on the subject of general design of reversing mill apparatus which is treated at some length in the paper. Generally speaking it is permissible to sacrifice efficiency to a slight degree in order to gain more rapid acceleration and for this reason it seems advisable to work all

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magnetic and current carrying material in the motor armature at the highest possible densities in order to reduce the stored energy to a minimum, the voltage being determined by the most economical arrangement of armature conductors and commutator segments. A decided advantage is gained by designing the motor with a view to cooling by means of forced ventilation. Valuable protection of commutators and brushes from the sharp steel mill dust and grit, as well as insurance from burnouts caused by deposits of this same material can be obtained by blowing sufficient thoroughly washed air through the motor for the complete ventilation of the dynamo room. As mentioned, before, it would seem advisable to let the voltage of these equipments be fixed by conditions governing the design of the motor rather than choose a voltage best suited to the generating set. The speed/voltage curves submitted with the paper apply fairly well to present day design but as the tendency is toward higher speed generating apparatus it is questionable whether they will apply a few years hence.

The rapid fluctuating speed and load conditions required by the cycle of operation of this type of equipment makes the question of rating, especially of the driving motor a rather vexed one. A very convenient working basis for heating can be taken as the maximum continuous safe load capacity at full field on the motor and maximum continuous generator voltage. If some such rating is established and the heating properly calculated from the rolling cycle for each installation much of the trouble which has been met in the past with electrically driven rolling mills will be avoided. Of course in addition to this it is necessary to make proper allowances for the range in load and speed as well as to carefully consider the mechanical stresses which are brought about by the rapidly fluctuating load conditions.

Peter Lindemann: There is one point in my mind which the schematic diagram shown in Fig. 3 of the paper does not make entirely clear.

It may be that there are other controlling devices used which are not shown in this diagram, and which will prevent the starting of the direct-current motors while the generator field rheostat is in neutral position, for it seems to me that the shifting of the brush holders on one of the direct-current separately excited generators would cause voltage to be built up on the closed motor circuit.

It would be interesting to know what precaution, if any, has been provided against such an occurrence.

Alex. Gray: One of the previous speakers brought up the question of the speed of the flywheel motor-generator set, and stated that whereas we use a speed of 375 rev. per min., European engineers have gone up to 500 rev. per min. for the same horsepower output. To me this would indicate one thing only, namely, that Eurpoean engineers work much closer to the limit than we care to do on this side.

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I once made the remark that there were limitations in the design of electrical machinery, and was told by a well known operating engineer that such limitations did not exist, and that as soon as the operating engineer demanded anything, the designing engineer found a way to overcome his limits and supplied the demand.

Mr. Hall in his paper has drawn attention to the fact that for each speed there is an output rating that cannot be exceeded unless the engineer is looking for trouble. This may be explained as follows: Taking a machine of given diameter, there is a safe maximum speed at which this machine may be run, and the output is then limited only by the length of the armature core. As this length is increased, the voltage generated in each turn of the armature also increases until, when a value of about 6 volts between adjacent segments is reached, interpoles become necessary. With inter-poles supplied, the machine may be further lengthened until, when a value of about fifteen volts is reached between segments, the machine becomes sensitive to changes in load and is liable to flash over. Compensating windings must then be supplied, if the output is to be further increased.

Evidently, then, the 500-rev. per min. European machine is run either with a greater peripheral velocity, or with a greater value of voltage between segments than in the case of the 375-rev. per min. American machine. From the fact that they are designed closer to the limit, much more care is necessary in the construction of the apparatus, so that the machine is not necessarily cheaper.

In regard to the rating of the motors, it must be clearly understood that while the motors in question have a rating of 10,000 h.p., at 100 rev. per min., they would become hot with a continuous output of about 4000 h.p. On the other hand, if the machines were large enough to dissipate the loss corresponding to a 10,000-h.p. load, they would have become so long as to operate badly with regard to commutation.

It is, therefore, rather hard to decide how they should be rated, because they are designed as 10,000-h.p. machines so far as commutations is concerned, and as 4000-h.p. machines so far as heating is concerned. Since the former is the more important limitation of the two, it seems reasonable to give them a rating of 10,000 h.p. maximum.

With regard further to the rapidity of reversal of the generator voltage, it is of interest to note that, since the machines have compensating windings, the air-gaps can be small, and the shunt excitation be almost negligible. It is, therefore, quite within reason to put a non-inductive resistance in series with the field coil circuit so as to reduce the time constant of this circuit and thereby allow the field to build up rapidly; and this would not reduce the efficiency of the machine to any appreciable extent, and, moreover, would allow the rate at which the machine builds up to be adjusted. It would seem from the discussion, however, that the machine reverses as rapidly as the mill engineer desires.

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Wilfred Sykes: The discussion by Mr. Pauly indicates lack of experience with this type of apparatus. The question of rating has been given considerable thought by engineers designing reversing mill equipments, both here and abroad, and it has been the practise to rate reversing mills on the maximum operating peak loads as it is these loads that fix the size of the apparatus, and not the continuous capacity based on heating. These loads do not represent the absolute maximum capacity of the machines without injury, but are the peaks that are ordinarily carried during the operation of the mill.

Mr. Pauly's remarks regarding the similarity of the reversing rolling mill and the mine hoist motors are correct as far as the general system used is concerned, but the operating characteristics of the reversing rolling mill motor, and the control problems are entirely different, and much more difficult than those of the mine hoist. The shocks which the reversing mill motor is subjected to are very much more severe than those of the non-reversing mill motor where the conditions are comparable, such as, for instance; the three-high blooming mill compared with the two-high blooming mill. In such cases the continuously running motor has a flywheel between it and the mill, and the shocks on the parts of the machine are very much less than with the reversing motor where the flywheel effect is reduced to a minimum.

Mr. Pauly's remarks about the speed of operation are answered very well by the discussion of Mr. Tschentscher. The same opinion was held ten years ago regarding the necessity for high rate of speed change, but after practical experience obtained with electrically driven mills it was obvious that extreme steps were not necessary to obtain high rate of reversal, and when Mr. Pauly has gained some actual experience with these mills, no doubt, his views will change.

The question of size of motor shaft, and upon which Mr. Pauly places so much stress, seems to be catering rather to the old idea of making a part massive without the appreciation of the conditions under which it operates. It is obviously useless to make the shaft many times stronger than some other part of the machine which is just as liable to be broken, and in designing equipments it has been our object to obtain the accumulated experience of motor and engine builders for this type of mill. A shaft diameter out of all proportion to the output of the equipment, or the size of the mill may be an excellent talking point in selling apparatus to an ignorant customer, but is not good engineering.

Regarding the discussion of Mr. Petty. It is not feasible to reduce the speed of the generator below certain limits, due to the fact that the flywheel diameter is limited by transportation facilities, and the flywheel effect necessary might mean prohibitive weights with speeds too low for economical design.

Mr. Lilgenroth brings up a number of points regarding the

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design of European compared with American reversing mills. The question of using one instead of two motors for the large equipments has received a great deal of consideration, and it was with a full knowledge of the European practise that the equipments now being built were designed with double motors. The question of safety to attendants is one on which a great deal of stress has been placed by mill operators, and there was a very great objection to the use of voltage higher than 600 across an individual machine. In the United States we must also face less skillful attendants, and the use of a 600-volt machine with 1200-volt insulation, such as the Bethlehem machine is, gives us a greater factor of safety than would be possible if we used single motors with, say, 1500 volts on the windings. The design features brought out, having been found desirable in Europe, are all incorporated in the machines which have been built.

The question of generator speed is one that has been given a good deal of thought, and it might be of interest to mention that the 500-revolution generators running at the Steel Company of Canada's plant repeatedly carry loads of 5000 kw. each, and it is quite possible to build generators for 500 revolutions to supply power to the motors at Bethlehem. On the other hand, using a speed of 375 r. p. m., there is greater leeway, and a greater margin could be obtained to cover the uncertainty of operation which was a factor on the Bethlehem installation. This mill was installed for rolling a very wide range of products, and different classes of steels, and it was practically impossible to predict before hand just how much power would be required. For this reason a conservative design was adapted, the wisdom of which has been shown by the operating conditions of the mill since installed.

Regarding the question of flywheels, we have found it desirable to limit the operating peripheral speed to approximately 300 ft. per sec., although the stresses at this speed are very low. This is due to the uncertainties as to the quality of metal obtained in castings. The conditions in the United States are very different from those in Europe where cast steel wheels, for higher speeds, can be readily obtained.

Regarding the question raised by Mr. Lindemann, provision is made in the controller for the generator fields to prevent the motors being started in the way he mentions.

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DISCUSSION ON "MOTOR EQUIPMENTS FOR THE RECOVERY OF PETROLEUM" (TAYLOR), CLEVELAND, OHIO, JUNE 27, 1916. (SEE PROCEEDINGS FOR JUNE, 1916.)

(Subject to final revision for the Transactions.)

F. Woodbury: About five or six years ago I was associated in the pioneer work near Los Angeles where some of these oil well motors were developed. We had considerable trouble owing to the prejudice of the operators against the apparatus, as mentioned by Mr. Taylor. They endeavored to discredit the motors by running full speed and reversing as fast as they could, doing everything possible to burn them out. However, in this they were not very successful, and we finally succeeded in successfully installing several motors.

The largest saving to be effected by motor operation is with producing wells which require pumping. Wells in process of drilling are comparatively few, so it is questionable if much is to be gained by using motors for this severe duty. An example of what was saved on the property where the development work took place is herewith given. Before electrification all of the natural gas on the property plus 30 to 50 barrels of oil was burned per day to produce the necessary steam for the pumping engines. After equipping 15 or 20 wells with pumping motors it was found no longer necessary to burn any oil, and there was an excess of natural gas. Electric power was supplied from a small plant receiving steam from the same boilers that were used to supply the pumping motors.

Mr. Taylor notes that there are many instances where it is hard to get motors installed due to local conditions not being suitable. This is quite true in cases where there is ample natural gas and the prospective customer is using gas engines. In other cases where crude oil is used for steam generation and the steam is piped considerable distances, large savings can be made by using motors.

A. M. Dudley: There is one fact that Mr. Taylor has not dwelt on, and that is the greater convenience of the electric motor. In such territories as the oil fields of West Virginia the hauling of a heavy steam boiler over the rough country is a serious problem. Six horses and even eight are often employed. You can readily appreciate that a motor occupying possibly 4 or 5 cubic feet and weighing not over 700 or 800 pounds is a most acceptable substitute.

Another point, is the great flexibility of the induction motor in the performance of any and all classes of work. It has been brought to your attention in connection with the paper on reversing rolling mills that in many cases the limiting factor of the d-c. motor is commutation. The induction motor has no commutation and for short time loads is limited practically only by the maximum torque it will develop. Mr. Taylor also shows that by connecting Y and Δ a maximum torque practically three times as great may be developed where needed for short

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periods in cleaning and "pulling." and that this is coupled with high efficiency when pumping continuously for days at a stretch. Another point brought out, is the possibility of connecting the same winding for two speeds and thus further adapting the motor to its work. From many points this is almost an ideal combination of motor and tool characteristics.

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DISCUSSION ON "EFFECT OF BAROMETRIC PRESSURE ON TEMPERATURE RISE OF SELF-COOLED STATIONARY INDUCTION APPARATUS" (MONTSINGER), CLEVELAND, OHIO, JUNE 27, 1916. (SEE PROCEEDINGS FOR APRIL, 1916.)

(Subject to final revision for the Transactions.)

R. W. Sorensen: Mr. Montsinger in presenting this most excellent treatise has placed before us a second set of data* for the purpose of enabling our Standards Committee to construct an accurate ruling, whereby the effect of altitude upon the heating of electrical apparatus may be determined.

In classing this as a second set of data, I have used that given by Frank and Dwyer as the first set, because in both these instances the test data used in arriving at the conclusions given, were derived from tests made largely at the same geographical locations; and also because the working up of these data was accomplished by the use of the same formulas of Dr. Langmuir's and others, as may be seen from a comparison of the paper by Mr. Montsinger with that previously published by Messrs. Frank and Dwyer.

Unfortunately, the results of the two investigations do not check as closely as would be desirable, as will be seen by the curves of Fig. 2. Also the curves obtained from these results do not approximate the A. I. E. E. rules (§308), as has already been pointed out by Mr. Montsinger in his paper.

For our assistance, therefore, I should like to present data of a series of heat run tests that I made on two oil-insulated self-cooled transformers. These tests were made at Schenectady, New York, Pittsfield, Mass., Grand Junction, Colorado, and Leadville, Colorado, with altitudes of 75, 345, 1525 and 3190 meters respectively, as indicated by barometer readings at the time and place of test.

The transformers used for the tests were rated 60-cycle, 125-kv-a., 11,000 volts to 2300 volts, and contained approximately 1300 pounds of active material (copper and iron). They were inclosed in corrugated sheet steel tanks with a cast iron base and wrought iron straps at the top for holding the corrugations in place. Each tank was about 5½ feet high, and occupied a floor space of approximately two feet by three feet in area.

The tests which I made, while not conducted in a special portable room, as were those of Mr. Montsinger, were conducted with special care as to uniformity of ventilation conditions in the large rooms of the factories and power plants where the tests were made. Observations were made of humidity at each place of test, and agreement of conditions in this respect found to be such that no corrections for differences of humidity were necessary.

*Frank and Dwyer "The Temperature Rise of Stationary Induction Apparatus as Influenced by the Effects of Temperature, Barometric Pressure and Humidity of the Cooling Mediums," page 235, A. I. E. E. TRANSACTIONS, Vol. XXXII.

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All heat runs were conducted by the standard motor generator method of loading two transformers for heat run, and readings of currents, volts and watts input to each transformer were made, to insure the accuracy of the knowledge of the watts to be dissipated, regardless of variations in wave form of voltage supply etc.

The results of these tests were as follows:

Place.	Actual watts loss.	Rise in oil deg. cent.	Rise in oil deg. cent. reduced to same loss 4820 watts
Schenectady	4820	36.0	36.0
Pittsfield	4820	37.5	37.5
Grand Junction	3965	32.5	38.9
Leadville	4570	39.6	41.8

From these results there is plotted on Fig. 1, curve *A* showing the probable change in temperature rise at various altitudes for a constant loss of 4820 watts in the transformers. The points located on the figure show the actual conditions as found by the tests made. Considering curve *A* on Fig. 1 as indicative of the true condition, it has been replotted as curve *D*, Fig. 2. Assuming, however, the test at Schenectady (36 deg. cent. rise) as correct and using this as a base, a greater influence of altitude is shown when the temperature rise of Leadville is compared with it and there results curve *E*, which has been plotted in Fig. 2, because it shows this condition, and also because it gives a possible conservative rule easy to follow, its slope being such as to show ½ of 1 per cent increase in temperature rise for each 100 meters altitude.

Applying to results of tests on these transformers Mr. Montsinger's method of analysis, we find the tanks were similar to those of Fig. 1. tank No. 2 in his paper, except in that the corrugations were spaced a greater distance apart. The tank dimensions were 65 inches (165 cm.) high over all, and had thirty-two 3½ in. (8.9 cm.) corrugations each, with a pitch of three inches (7.62 cm.) per corrugation, making the developed surface as follows:

*Corrugations	$4 \times 66.5 \times 55$	14,630 sq.in. (94,500 sq.cm.)
Upper plain band	$4(29+24.75'')$	426 " " (2750 " ")
Lower plain band	$6(29+24.75'')$	640 " " (4130 " ")
Envelope surface	$= 65(29 - 24.75'')$	= 6950 sq. in. (44,900 sq. cm.)
		15,696 sq. in. (101,330 sq. cm.)

Therefore:

$$(\text{Leadville}) = \frac{5.6 \times 3.19}{1 + 1.3\ (6950/15696)} = 11.3 \text{ per cent.}$$

*66.5 inches is the developed length of each one of four sheets of steel, making up the corrugated walls of the tank.

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At first sight this result does not appear to check very closely the tests made upon the 125-kv-a. transformers as will be seen by comparing curves *D* and *E* with curve *C* of Fig. 2. A very careful consideration, however, of the data obtained from the tests on the transformers shows a possibility of a very close agreement between these and the results obtained by Mr. Montsinger.

At the time the tests were made on these transformers, it was feared that in moving about from place to place it would not be possible to have a fixed set of conditions at each place, and consequently a number of heat runs at different loads and voltages were made at Pittsfield (altitude 345 meters). These many tests, carefully made and checked with each other make them

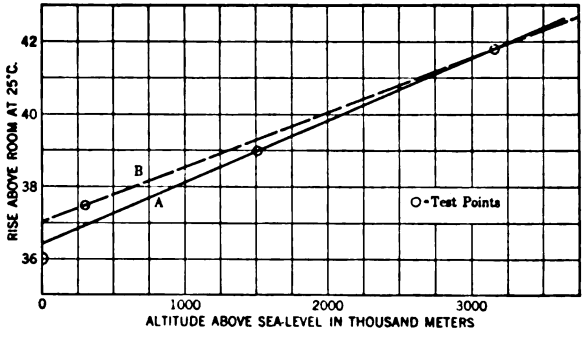

FIG. 1—TEMPERATURE RISE OF 125-KW., 11000-2300-VOLT TRANSFORMERS DUE TO CHANGE IN ALTITUDE.

CURVE A—PROBABLE TEMPERATURE RISE CURVE FOR 125-KV-A. TRANSFORMERS AS OBTAINED FROM ALL FOUR TEST POINTS

CURVE B—PROBABLE TEMPERATURE RISE CURVE FOR 125 KV-A. TRANSFORMERS AS OBTAINED WITH TESTS AT PITTSFIELD AS BASIC

worthy of consideration in establishing a basic "rise of temperature."

With the temperature rise for a loss of 4820 watts determined at Pittsfield as a base, the possible temperature increase curve may be drawn through the Pittsfield and Leadville points as of curve *B*, Fig. 1. This curve shows a rise of 37.5 deg. at sea level, which means an increase in temperature rise of approximately 1.2 per cent at Pittsfield over that of Schenectady.

By Mr. Montsinger's formula:

$$\phi \text{ (Pittsfield)} = \frac{5.6 \times 0.345}{1 - 1.3\ (6950/15696)} = 1.22 \text{ per cent.}$$

With probable rise of 37.05 deg. cent. at sea level (Schenectady) and a rise of 41.8 deg. cent, at Leadville, there is an increase in temperature rise at Leadville over that at Schenectady (sea level) of 4.75 deg. cent. or 12.8 per cent, which compares favor-

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ably with the increase of 11.3 per cent as obtained by the use of Mr. Montsinger's equation 17, and we can draw curve K as a possible curve for the 125-kv-a. transformers as of the tests made in June, 1910.

It is quite probable, therefore, that the curve E is somewhat high, and that practically all self-cooled oil-insulated transformers would give results within the range limited by curves C and D.

These facts show very clearly that Mr. Montsinger's paper

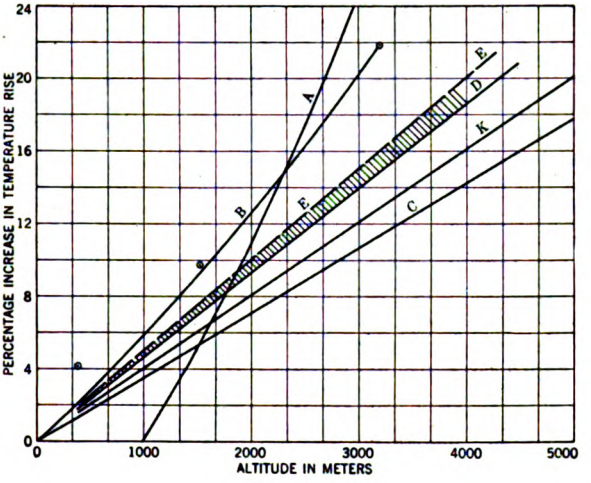

FIG. 2

CURVE A—1915 (ART. 308) A. I. E. E. RULES

CURVE B—FROM TABLE II D, FRANK & DWYER, PAGE 254, A. I. E. E. TRANSACTIONS, VOL. XXXII

CURVE C—VALUES FOR 125-KV-A. TRANSFORMERS OBTAINED BY EQUATION 17, MONTSINGER, A. I. E. E. PROCEEDINGS, APRIL, 1916.

CURVE D—VALUES FOR 125-KV-A. TRANSFORMERS OBTAINED FROM TESTS, AS OF CURVE A, FIG. 1

CURVE E—FOR SUGGESTED RULE OF ONE-HALF OF ONE PER CENT INCREASE FOR EACH 100 METERS ALTITUDE

CURVE K—VALUES FOR 125-KV-A. TRANSFORMERS WITH THE TESTS AT PITTSFIELD BASIC, AS OF CURVE B, FIG. 1

has advanced us materially in the solution of this problem, but it seems hardly advisable for the following reasons, to adopt the recommendation as given in his paper whereby his equation 17 is to be used. His Fig. 7 shows that for a shape factor of 0.9 a curve that practically coincides with curve E, Fig. 2. Also it is possible that there may be conditions governing the oil circulation of actual transformers different from those of the experimental apparatus used by Mr. Montsinger in obtaining his results, so that some curve between curves E and C of Fig. 2

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would more nearly approach the average results of a large number of transformers of various designs.

I would recommend, therefore, that, until further information can be obtained, an increase of temperature of one-half per cent be allowed for each 100 meters altitude, as this will be more nearly correct than the present rule and will at the same time allow ample margin for safety as the $\frac{1}{2}$ per cent is undoubtedly somewhat in excess of the necessary allowance.

A. I. E. E. rule § 308 would then read the same as at present with the exception of the next to the last sentence which would read about as follows:

It is recommended that when a machine is intended for service at altitudes above 1000 meters (3300 feet) the rise in temperature shall be determined, until more nearly accurate information is available, by adding to the rise at sea level one-half per cent for each 100 meters (330 ft.) of altitude.

Alexander Gray: If duplicate machines are tested by different men for temperature rise the results will differ. Accurate measurement of temperature is not easy and any small error in reading will give results from which it will be impossible to deduce any law of cooling.

I once started some work on the heat dissipation from vertical surfaces but without great success. The apparatus consisted of a wooden cylinder on which strip copper was wound and the surface temperatures were determined by resistance measurements. By juggling coefficients I finally obtained a radiation coefficient of about 0.75 and a law of convection that agreed accurately with Lorenz law. I am inclined to think, however, that I was looking for such a law and adjusted the radiation coefficient to suit and, having come to that conclusion, I decided thereafter to leave the subject to the physicist.

There has recently been developed at the Bureau of Standards an instrument by means of which the actual radiation from a surface may be determined so that the field looks promising for those interested in heating problems.

It is of interest to note that in the report presented by the Transmission Committee, the Trinidad Company states that, at high altitudes, transformers ran ten per cent hotter than normal while rotating machines ran only five per cent hotter and yet the rotating machine is that in which nearly all the heat is dissipated by convection.

When heat is dissipated by means of air blown over a surface a reduction of the density of the air causes an increase in its temperature but this does not necessarily mean that the surface temperature is increased by the same amount. There is a large temperature gradient between the surface and the air about which we know very little and because of this I do not believe that we are in a position to make any recommendation as to the correction to be made for barometric pressure.

Experimental data such as those contained in Mr. Montsinger's

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paper add to our knowledge of a very difficult subject but I believe much more of such work is necessary before we are in a position to make more than a recommendation as to the correction for barometric pressure.

V. M. Montsinger: In reference to Prof. Sorensen's discussion, although the curve which he considers most reliable checks very closely the results I obtained, he does not recommend a correction in accordance with the formula, but recommends one correction for all transformers, which is slightly less than the maximum correction by the formula. He states that it will take care of all the cases which come up. That is true. My point is, however, and I have tried to emphasize it, if we have only one correction factor for all types and have one transformer for which the correction is only about 7 per cent as is the case for a tank having plain surfaces, for a difference of 10,000 ft. in elevation, it is not necessary to design this transformer with a margin of 15 or 20 per cent. I believe that it is advisable to adopt some formula that will take care of this difference, because if we attempt to continue to make one correction for all types of apparatus, especially for stationary and moving types, the problem will still remain in a very unsettled condition.

Regarding Prof. Sorensen's statement that the conditions may not have been the same, where I heated the tanks by means of resistance tubes, as are the conditions in an actual transformer. This may be true if we considered only the windings of the transformer and depended on them (or the resistance tubes) for comparative temperatures. Due to the uncertainties of obtaining accurate resistance measurements, the top or maximum oil is usually, for comparative purposes, the better criterion. This has been used altogether in comparing observed with calculated values. In order then that this means of heating the tanks affect the accuracy of the readings as compared with an actual transformer, it would be necessary that the temperature gradient of the oil, as affected by barometric pressure, change more under the one condition than under the other condition. There does not seem to be any logical reason why this should be the case.

I agree with Mr. Gray that it is very hard to obtain an accurate law covering the effect of barometric pressure on heating, because in practise this correction is usually small and there are always errors which are liable to creep in. For that reason I do not think we should base any conclusions on, say one test. For my observations, there were three different tests made on each style of tank. An examination of the tabulation of the results will show that although the tests vary slightly, which is to be expected, there are no large variations. This would indicate that the method of making the tests was considerably more accurate than the method usually used in practise.

It is under any condition a difficult matter to separate radia-

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tion from convection, but the law for radiation has been fairly definitely settled and convection follows somewhat the same law, but for smooth surfaces the problem is not as difficult as it would be if we attempted to separate the losses from moving machinery. For the latter condition, the surfaces are more irregular and we do not know the laws, as a whole, under which the heat is thrown out from the machine into the air.

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DISCUSSION ON "THE EFFECT OF HIGH CONTINUOUS VOLTAGES ON AIR, OIL AND SOLID INSULATIONS" (PEEK), CLEVELAND, OHIO, JUNE 29, 1916. (SEE PROCEEDINGS FOR JUNE, 1916).

(Subject to final revision for the Transactions.)

John B. Whitehead: We have again to acknowledge our debt to Mr. Peek for a most valuable contribution to our knowledge of the electric strength of air, and now also that of liquid and solid insulation.

Referring to Mr. Peek's observations on the comparison of alternating and continuous voltage at which corona appears, I have recently been conducting, in conjunction with Mr. W. S. Brown, a series of similar experiments. The results of these experiments show some variation from those obtained by Mr. Peek.

The expressions for the critical corona voltage in terms of the diameter of the conductor, as given by Mr. Peek and as given in my several papers on "The Electric Strength of Air," differ somewhat but not widely. Experiments by Farwell and others on corona forming continuous potentials differ as between positive and negative potentials, and reveal some question as to whether there is any agreement between alternating and continuous corona potentials. In view of these differences our experiments have aimed to take alternating and continuous observations on the same apparatus, under the same conditions and with the electroscope and such other precautions as to measurement as would insure accurate results. The method used for obtaining d-c. potential is the same as that shown by Mr. Peek in the lower half of Fig. 1. That is, we have used a kenotron with one side of the circuit grounded. Our experiments have differed, however, in the method of measuring the continuous voltage. For this we have used a standard d-c. Weston voltmeter, with series-connected, non-inductive-resistance aggregating a million and a half ohms. Mr. Peek, apparently has depended on the ratio of transformation of his high-tension transformer as an indication of his d-c. voltage. For our alternating voltages we have used the ratio of transformation of the transformer together with careful oscillograms on the low-tension side for determining the maximum values.

Our results show a marked difference between positive and negative corona voltages for a range of wires between 0.07 and 0.23 cm. diameter. When the wire is negative the corona forming voltage within this range varies from 6 per cent to about 2½ per cent higher than positive. Mr. Peek states, as shown by Table II that within the corresponding range and indeed throughout the entire range of his observations, there is no difference between positive and negative corona forming voltage.

Mr. Peek, as usual, has contributed a most interesting paper. In my opinion the value of it would be greatly enhanced if it

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contained a better description as to the conditions of accuracy under which the observations were taken. For example, a static voltmeter seems to have been relied on for the continuous voltage measurements. My experience with this type of instrument leads me to feel that it is far from accurate. One would also like to know the general conditions under which the maximum value of the alternating voltage was determined on the low voltage side and how often throughout the range of voltage used. No statement is made as to how closely any of the observations may be repeated. In connection with the puncture tests on solid insulation it would be particularly interesting if Mr. Peek has been able to secure uniform results with repeated observations of the puncture tests on single sheets of material.

One must always envy the exceptional facilities which Mr. Peek is able to bring to bear on his experimental problems. A uniform source of continuous potential up to 150 kv. offers promise of many valuable observations.

William Baum: Whenever the subject of high continuous voltages has come up in the past in the engineering societies it was admitted with regret that we had no definite data on d-c. corona and puncture voltages. We know now with certainty that the d-c. puncture voltage is 2.5 times the a-c. maximum puncture voltage, or 3.5 times the a-c. effective voltages for an insulation thickness of 1.2 mm. where the time of test is a maximum.

This brings back to my mind the old claim of Mr. Thury and his followers that an effective alternating pressure of 10,000 volts imposes on insulation a stress of the same order of magnitude as a d-c. pressure of 25,000 volts.

It appears now that Mr. Thury was right when he claimed that d-c. cables require less insulation than a-c. cables designed for the same voltage, so that if d-c. voltage has advantage of lower disruptive effects, as Mr. Peek has shown for normal operating conditions, this would make the application of high-tension d-c. current for transmission purposes more favorable. Indeed the Thury system, although it has met with some criticism in this country, has further advantages which, I believe, have never been pointed out sufficiently until the present time.

Without wanting to go into the details of the high-tension d-c. system for transmission, I take this opportunity of calling attention to the multi-circuit feature which makes a constant d-c. system especially efficient for inter-connecting a number of stations, systems or net-works for the transfer of power. One of the most important applications would be that to long distance railroading, as transcontinental lines, by inter-connecting by such a series system the substations in the railroad, and all available sources of power near the railroad.

Mr. Peek has suggested the testing of cables by direct current, and I agree with him that faults in cables installed could be found just as easy or easier with direct current than with alter-

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nating current. Anybody who has had to do with cable testing in installations appreciates the independence of the source of electric power which would exist if we could make use of the kenotron rectifier described in the paper in connection with a small transportable gasoline-electric set, or similar high-tension direct-current rectifiers which have been in use abroad for a number of years, and which are known as the Geoffroy & Delore and Delon apparatus. In fact, the Siemens-Schuckert works have made puncture tests with their Delon rectifier which check very close with Mr. Peek's own exhaustive and defined experiments.

I believe that Mr. Peek should continue his investigations and extend them over long lines of cables which have been installed, so that no doubt may arise in the minds of those who question the applicability of high-tension direct current; for testing purposes and transmission systems.

Stanley Farwell: I can remember when I was working on corona that I went to Mr. Peek's papers and Dr. Whitehead's papers and used them more or less as text-books. My work has been entirely with direct-current corona, and on that account I am unable to make any comparison between that and the alternating-current corona. In my work it did seem to me that the d-c. corona lends itself better, perhaps, to the study of the physical nature of corona than does the alternating current.

In the work I did, I started out to do certain definite things, but I found as I went along, the things I started to do got further and further from me, because I ran into so many new things that apparently had not been explained. I went to one of the best physicists I knew and got him to try to help me out on the physical explanation of the formulas such as are given in Mr. Peek's papers and Dr. Whitehead's papers and my own. I found, after a while, that we got up against a stone wall.

At the University of Illinois, they are now working on some further experiments, and are taking different gases, trying to study them, and get some knowledge of the physical laws underlying corona. I used air entirely, and I found that when working with parallel cylinders, the change in the composition of the air, due to corona, seemed to cut quite a figure. We are now trying to get away from that by using simple gases.

C. E. Skinner: All of us who have had to do with insulation and insulation testing have many times wished we had available direct current so that we could get away from some of the complications which constantly beset us in the testing of insulation with alternating current. We have variables enough without the extras that come in due to the variations from frequency, wave form and things of that kind. Insulations are about the most difficult things to investigate, because of the fact that there are such an enormous number of variables coming in to mask results.

Our own work has been more along the line of the measuring

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of the losses at high voltages. The condition we have to meet in practise is that we have stresses due to alternating current and some of the important features in connection with this phenomenon are in connection with losses which occur in the insulating material.

For some time I have had some experiments going on with a view to seeing if we could not determine beforehand when insulation was in condition to break down, before it actually broke down. All of our early work was based on breakdown values after the breakdown occurred, and I am very pleased to see that some recent work indicates the possibility of predicting very definitely when insulation is in a condition to break down, before it actually does break down, by a fairly simple measurement of power factor and losses.

Mr. Peek's paper brings out a new method. It gives us a new rule. With each new instrument we enter a new field of investigation, and I am very sure that this paper marks the beginning of a very important era of work along these general lines.

Chester L. Dawes: Mr. Peek has produced some very interesting and important results, but I should like to add to, or amplify some of the explanations which he presents. In Fig. 6 which shows the spark over between concentric cylinders, the 60-cycle curve gives low values of voltage for small values of r; these values increase to a maximum with increase in r after which they decrease. That is, the greater thickness of air has a lower dielectric strength than the thinner layer until a certain ratio of R/r is reached. At first this does not seem reasonable, but the following explanation to me seems rational. The impressed voltage

$$E = \frac{g\, x \log_{10} R/r}{0.434}$$

where g is the gradient at which air breaks down, and x is the radius to the air where the gradient is g. This assumes that the corona has the effect of increasing the diameter of the conductor to x. If this assumption were correct the voltage E could be increased until $x = \frac{R}{\epsilon}$ before spark over would occur. Therefore it would seem that the spark over voltage would be the same for all central conductors whose radius $r \leq \frac{R}{\epsilon}$. That is, the relation if plotted would be similar to the upper d-c. curve shown in Fig. 6. However the corona surrounding the central conductor is not the same as a metallic conductor of the same diameter for no corona would exist about the metallic conductor. The corona formation about the smaller wires is emitting ions that are projected into the outside layer of air which is supporting the stress. These ions produce others by collision, etc. and the outside layer of air breaks down at a much lower voltage than it would if the corona formation had acted

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like a metallic conductor. The smaller wires produce a larger number of these ions and a lower spark-over voltage results as shown in Fig. 6. I should like to ask if any reason can be given for the d-c. voltage following a different law than the a-c. in Fig. 6.

As Mr. Peek states, solid insulation like cambric may behave quite differently when tested with d-c. than it does when tested with a-c. which partly is due to the fact that the insulation is composed of an infinite number of minute capacitances and conductances arranged in various series-parallel combinations. When a direct current is impressed across a piece of insulating material there is an initial rush of displacement current which drops off very rapidly at first and then more slowly until after some time it reaches an essentially constant value. This decay of current is almost logarithmic. It may be several minutes before the current reaches its constant value. The above phenomenon is often called "absorption." It is due to the minute condensers constituting the insulation, being charged through high resistances. Therefore the voltage distribution in the insulation will be materially different at the end of charge than it is at the beginning and with alternating current. At the end of charge the distribution is determined entirely by the conductance relations in the insulation and at the beginning of charge and also with alternating current the distribution of potential is determined almost entirely by the capacitance relations in the insulation. It would seem reasonable therefore to find the short time d-c. tests checking more closely than the a-c. tests. The fact that they do not, I should say was due to the fact that the period of two seconds or so was long enough for the direct-current distribution of potential to assume very nearly the final steady state.

The author shows that d-c. breakdowns are practically the same as the a-c. breakdowns when the insulation has a low resistance. Outside the question of the alignment of moisture particles, I believe that the explanation lies again in the manner in which the potential distributed itself through the insulation. When the resistance is low the a-c. distribution of potential is determined more by resistance than it is by capacitance, so the breakdown should be more nearly the same as it is with direct current. This is also true in transil oils. The best grades have a much lower insulation resistance than other well-known solid insulators. Also the oil molecules being mobile, can quickly arrange themselves to make the capacitance a maximum. Therefore little "absorption" can be found in oils.

I should not recommend that direct current be used for testing cables except perhaps in a few instances. It might be applied to homogeneous single-conductor cables provided that sufficient allowance be made to account for unknown hysteresis effects and the foregoing factors. I believe that the heating is negligible at ordinary frequencies. It would be out of the question

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to test graded cables and the ordinary twin-conductor and multi-conductor cables with direct current, as the voltage distribution throughout the various insulations when in service is determined by the capacitance relations whereas, in the d-c. testing it would be determined by conductance relations.

Clayton H. Sharp: As I understand it, Mr. Peek advocates the use of continuous voltage for cable testing for the reason that under certain conditions the continuous voltage is more severe on the cable than the alternating voltage, whereas yesterday, he objected to the use of the high-frequency oscillatory voltage in testing transmission insulators for the same reason.

John B. Taylor: Has comparison been made between the voltage as determined by the transformer ratio; by electrostatic voltmeter; and by what, at first sight, would be the normal way to measure the high d-c. voltages,—plenty of resistance and standard d-c. voltmeter?

In work with extra high-voltage alternating current there has been much doubt as to the correctness of the values of high voltages, so it is surprising to see in a presentation of d-c. high-voltage experiments the reliance which is placed on a-c. instruments, ratio of transformation and the electrostatic voltmeter.

The Thury system of d-c. series high-voltage transmission of power has been referred to. Service experience in Europe extending over a number of years has demonstrated the practicability of working underground cables and other insulators under continuous voltages higher than has been attempted with alternating current. This advantage of the Thury system from the insulation standpoint has been well recognized and there are other advantages such as opportunity to save copper by using earth-return circuit without inductive disturbances to telegraph and telephone lines. Lack of flexibility in distribution to many consumers unfortunately has interfered with more general introduction of the system. Mr. Peek's curves in Figs. 12 and 13 indicate how much more a cable may be expected to stand under d-c. stress than a-c. stress. Similar tests should be made on completed cable samples containing splices and for much longer time than the 1500 seconds.

Continuous high voltages (higher even than the 150 kv. of the paper) have long been available from "friction" and "influence" electrostatic machines. Large numbers of small storage cells have been connected up, and series of small d-c. generators have been assembled for experiments and testing at voltages at one time regarded extremely high. The complication of many small d-c. generators and the bulk, unreliability and small power output from static machines possibly makes the use of a-c. generators with step-up transformer and rectifying "kenetron" the most practicable high continuous d-c. experimental device.

Cable failures occur principally at splices due to,—cracked insulation from bending and handling; damaged insulation from overheating (drying out, soldering, lead wiping, or hot compound);

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insufficient insulation thickness or poorer grade at splice than in run of the cable; introduction of moisture; presence of air cavities (possibly at reduced pressure resulting from contraction of compound on cooling.)

These different weaknesses probably have different ratios for standing a-c. and d-c. stresses. Particularly an air space in the field between conductors might be expected as result of continued thermal or chemical local action to fail more readily on a-c. stresses. Mr. Peek suggests testing cables with direct current of value equal to maximum of accepted a-c. testing values. His results in Figs. 12 and 13 would seem to call for a higher direct current than this. Perhaps twice the effective a-c. voltage would be comparable.

F. W. Peek, Jr.: Referring to the questions of Dr. Whitehead and Mr. Taylor, the voltages were checked by means of a known liquid resistance in series with a milliammeter, and also by a known resistance in series with an oscillographic vibrator, across the high-voltage lines.

Dr. Sharp misunderstood my remarks on "high frequency." I think my meaning will be clear when reference is made to the written discussion.[1] I did not condemn high-frequency tests, as such, but gave an illustration to show how easy it is to misinterpret the results of such tests.

I have not advocated direct current for cable testing. I have simply pointed out that it looks very promising, for the following reasons:

I. Air, oil and insulating liquids break down at d-c. voltages equal to the maximum a-c. voltages.

II. Solid insulations containing moisture break down at approximately the same maximum voltages on alternating and direct current.

III. Solid insulation, *in good condition*, require a direct-current voltage much higher than the maximum alternating-current voltage to cause breakdown.

It thus seems that most faults will be located equally well on a-c. or d-c., if a d-c. voltage equal to the maximum of the a-c. testing voltage is used. This follows because large cracks filled with air or oil will be broken down at the same maximum voltage on a-c. or d-c. (see I above); wet insulation will break down at approximately equal voltages on a-c. or d-c. (see II above); injury is much less likely to occur to solid insulation in good condition on d-c. (see III above).

Although the laboratory tests indicate very promising results, I believe it important that practical experience be gained in the field, before recommendations are made for extensive or general use of this form of testing. Naturally, the principal use of the d-c. test would be in the field where a portable set is necessary. All cables should be given the a-c. test in the factory.

1. Discussion of papers of Messrs. Creighton and Marvin, Cleveland, June 27, 1916.

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When the fault occurs in the cable it is often desirable to burn it out to low resistance so that its position can later be located by a bridge. Our laboratory tests indicate that this can be done with the d-c. testing set. The time required to burn out a fault in this way depends upon the condition of the sheath. If the sheath has been broken open a greater time will be required than if the sheath is intact. The time will vary from 1 to 5 minutes.

In making the d-c. corona tests we found, as a rule, that the visual corona point was quite sharp and definite when the wire was positive. When the wire was negative, however, it was often quite difficult to determine this point definitely. The slightest surface irregularities cause the negative corona to brush at fairly low voltage. It is quite possible that the negative corona voltage is a few per cent higher than the positive corona voltage, the exact difference, however, if there is any, will depend to a considerable extent, upon the observer and what is defined as the critical point.

L. T. Robinson: I think one of the greatest advantages in cable testing by direct current is that you can get along without an undue amount of apparatus—you are required to furnish only the energy for testing the cable and not a big charging current, and therefore you do not need a big 50-kw. transformer to test, a small cable, but maybe a 3 or 5-kw. transformer, which is a great advantage. There is not so much to lug around.

F. W. Peek, Jr.: I wish to say, as a matter of interest, that it may require from 1000 to 2000 kv-a. to test long lengths of cable on alternating current whereas similar tests may be made on direct current with from 3 to 5 kv-a. That is one of the reasons why d-c. testing suggests itself, and why, I believe, it is worth trying out in practise. It will often be a question of a d-c. test or no test at all, and not which is best.

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DISCUSSION ON "THEORY OF PARALLEL GROUNDED WIRES AND PRODUCTION OF HIGH FREQUENCY IN TRANSMISSION LINES" (CREIGHTON), CLEVELAND, OHIO, JUNE 29, 1916. (SEE PROCEEDINGS FOR JUNE, 1916.)

(Subject to final revision for the Transactions.)

Harold S. Osborne: In considering any circuit which uses the ground as part of the electric circuit, we are forced to take account of a factor which in the present state of the art is to a considerable extent unknown, that is the property of the ground itself. The ground is not a perfect conductor, and in a great many instances in which the ground is used as a part of the circuit, the effect of the resistance of the ground is very considerable.

In dealing with currents of a few hundred or a few thousand cycles, we have found that as to electrostatic effects the resistance of the ground usually has but slight effect. The determination of what the equivalent level of the ground is, is sometimes difficult. For example, a row of trees may have a considerable electrostatic effect, and would be very difficult to take account of in mathematical work. In electromagnetic effects, the resistance of the ground is, for currents of the frequencies of which I have spoken, ordinarily very considerable. We have found in some cases that a grounded circuit produces the same effect as though the return current were concentrated at a point a thousand feet below the surface of the earth, and in some cases a considerably greater distance, and I would be very much interested if Mr. Creighton can give us any information regarding the effects of the ground at these very high frequencies which he is discussing.

The other point I had in mind is an effect of the use of overhead grounded wires of which the author does not speak—the overhead grounded wires not only tend to protect the power lines from induced charges from clouds, but also tend to protect the circuits paralleling the power lines from charges induced by the power circuit. This effect is very considerable in some cases, and I am sure that telephone engineers should be pleased that Mr. Creighton is advocating their more extended use.

N. S. Diamant: I think it is well in connection with this paper to call attention to the advantages of investigating graphically electrostatic effects of ground wires, at least in the simple cases; the advantage of the graphical method is its simplicity and especially the fact that it gives a picture of the electrostatic stresses existing in the space near the ground and transmission wires.

From the nature of the subject, I think it is a serious defect not to have included in the paper references to previous work and to detailed mathematical and graphical solutions. The fundamentals on which the treatment of the subject is based are given in the monumental works of Maxwell. However, without going to original sources it would have added greatly to the value

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and usefulness of the paper to have a few references; even if the author used no references whatsoever, it would not have been as difficult for him to look up some, as it will be for any reader who may desire further details.

As Mr. Creighton has emphasized there are important assumptions to be made which are not unassailable and on which differences of opinion may exist. The results of this paper depend on these assumptions which Mr. Creighton has so clearly brought out. Now, references, no matter how incomplete, would have allowed us to compare some of the author's assumptions and results with those of others.

John B. Taylor: I must confess to being somewhat confused in following this paper, through the use of some of the terms. For instance, when we are discussing periods of time as brief as a millionth of a second, what is the interpretation to be put on such words as "instantly" and "suddenly." I judge Mr. Creighton wants us to assume that a charge accumulates in a cloud gradually through moisture condensation or other atmospheric condition, and that equally gradually the ground wire and the conductors of the line accumulate charges by induction from the cloud. Then "suddenly" without regard to time, it is assumed that the charge on the cloud, disappears in a lightning stroke, leaving the charge on ground wire to oscillate at its own natural period as determined by the conditions of the circuit,—distance between earth connection and the inductance and capacity involved.

A different state of affairs seems more consistent with his estimated length of lightning stroke as one mile. How is it possible to be rid of the charge on the cloud through a stroke a mile long in a time negligible compared with the time of oscillation in the overhead ground-wire circuit, which is given, in a 500-foot span, in the order of two million cycles per second.

The transfer of the cloud charge over a mile will take, in round figures, ten times as long as for the overhead wire charge to reach earth through the connection provided at 500-foot intervals. From this the release of the induced charge on the ground wire should follow the cloud discharge and be practically a periodic, instead of setting up oscillations of the order of millions of cycles.

In discussing the early use of overhead ground wires, Mr. Creighton may have overlooked the long established practise of the American Telephone & Telegraph Company. The "zero" wire on the tops of the poles served for lightning protection, mechanical stability, and convenience in testing. Mr. Creighton points out that a small wire is almost as effective as a large wire, as regards its electrostatic effect, but mechanical strength and ability to discharge heavy strokes without fusing are important factors. In some early installations poor material and flimsy construction gave more trouble than was prevented. There was a time when ground wires were in disfavor, but they

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have come into favor again, only after recognition of the need for good mechanical construction.

John B. Whitehead: It is interesting to remember that ever since the days of Benjamin Franklin, scientists, physicists and engineers have studied lightning phenomena, but no satisfactory explanation or theory has resulted. It is impossible, of course, to control the conditions in the natural case, and hence experience is limited to inadequate laboratory studies. Therefore it seems to me that it is quite proper to build up assumptions which come as near to actual conditions as our existing theories indicate, and then to compare the results following from them with the natural case.

Several years ago a paper was read before the Institute by Mr. J. P. Jackson, in which he made an effort to plot the equipotential surfaces of a transmission line with ground wires upon the towers. The surface of zero or ground potential, was shown to have different shapes in accordance with the different positions of the ground wire. The whole question reverts of course to Faraday's original proposition, which has been justified by experience in a hundred ways, that if you want to protect anything from lightning or from electrostatic influences surround it by a grounded cage. The grounded wire is simply a small approach to that condition, and therefore taking the condtitions Mr. Creighton outlined in his abstract, it is perfectly natural that the nearer you put a grounded wire to the transmission wire just so much more nearly do you give it a grounded screen.

I question the correctness of one of the conclusions, namely that the grounded wire placed below the power wire should give it approximately as much protection as when the grounded wire is placed above it. Naturally, there would be some, but I think the difference should be quite considerable for all but the smallest distances of separation. Otherwise, the conclusions are in accord with the conception that the grounded wire, is simply an approximation to a grounded cage.

The author questions whether a lightning rod should be pointed, since when the corona starts from a point it is equivalent to making the wire blunt ended. My conception of the point of the lightning rod is that it gradually dissipates the charge as the potential rises by the discharge from its points, and consequently tends to keep down the potential. I should, therefore, question whether a blunt point would serve so well as a sharp point.

L. W. Chubb: The author speaks of the peaking of the charge, illustrated in Fig. 8, causing a displaced negative charge which forces a charge in the windings of the apparatus in an undesirable way. I understand that this menace only exists for the ungrounded system.

E. E. F. Creighton: Yes.

L. W. Chubb: Mr. Taylor has called attention to the relative time constants of the short line sections and the long lightning

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path, precluding the possibility of propagated wave trains and the more probable existence of sloping wave fronts. This is, I think, an important point and the analysis of lightning phenomena should be made assuming only factors of the proper order of magnitude.

In Fig. 14 Mr. Creighton has shown the parallel ground wire divided into short sections by the grounding wires, and each having an electrostatic capacitance to ground. At the time of discharge from cloud the freed charge in each section will divide and pass out the grounding wires as shown. The currents in the adjacent sections will induce in the power line traveling waves in opposite directions, which will result in standing waves. If the induced waves in the power line are nearly in phase there will be a rather complete cancellation of the waves and a falling off in amplitude along the line as it passes outside of the influence of the cloud. This cancelling effect and the damping in the circuits would seem to be enough to limit the wave trains beyond the influence of the cloud to a rather insignificant amplitude. There is also some doubt in my mind whether the released charge in the section of the ground wire will oscillate, because the capacitance is not concentrated as shown in the figure. The section has distributed capacitance and inductance. If the distributed constants of the section of the ground wire do prevent the propagation of wave trains in the power line, the standing waves will not exist and the bad after effects of the ground wire would be reduced to a very sloping wave front of much less amplitude than if the ground wire were not present.

In several places in the paper the author, in pointing out the inductive effects of the ground wire on the power wire, speaks of the sudden change in capacitance to the line. Capacitance is an invariable physical constant and I cannot see how a change in capacitance takes place during the transient.

E. E. F. Creighton: I am unable to give Mr. Osborne any experimental information on the distribution of high-frequency currents in the ground. I am glad Mr. Osborne added another use of the overhead grounded wires which I had overlooked.

Referring to Mr. Diamant's request for a bibliography I have to confess that I did not make one and in fact did not attempt to look up all the references. The mathematical equations, as originally given by Maxwell and Heavyside are available to those who have the volumes. These I have not referred to for many years. The work by Heavyside will be found in one of his two volumes of "Electrical Papers."

Referring to Mr. Taylor's comments—I endeavored to simplify this matter by considering only one variable at a time. The neglected factors are, I believe, stated in the foot note. The words "instantly" and "suddenly" then refer in an indefinite way to the period of time corresponding to the length of charge in the constants of a circuit. In reading the paper it should be

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kept in mind that in the beginning all factors that could be set aside were neglected and subsequently each one of these was considered, although they were not all combined, as it would make the subject too complex.

Referring to Dr. Whitehead's skepticism on the protection given by an under-hung wire—I can only recommend to him that he make the calculation to be convinced.

Referring to Mr. Chubb's last paragraph in his discussion—it is impossible to come to any definite understanding because of the several different definitions given for capacitance. If one defines capacitance as the quantity per unit difference of potential then Mr. Chubb's conception of the invariable physical constants will hold only when there are two electrodes, namely one positive and one negative. We often think of capacitance as certain dimensions, as is always true in a single condenser but when there are three or more electrodes then capacitance is determined not only by the physical relations but also by the relative potentials of the conductors. I have worked out many examples to prove this statement. The calculations are too long to include in this discussion. This paper was shortened more than 50 per cent by curtailing the mathematical work and calculations. I can hardly hope to have deleted this material judiciously in every case although I hope I have put enough mathematical work at the end of the paper to suffice for the understanding of the equations used.

In the shortening of the paper I noticed subsequently that I made a mistake on page 966 in the second equation where I use the equation for protection $\frac{b}{a}$ when it should have been the ratio of the potentials as given in the equation at the bottom of the page 964. This matter is correctly stated in the mathematical work at the end of the paper.

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DISCUSSION ON SUGGESTIONS FOR ELECTRICAL RESEARCH IN ENGINEERING COLLEGES" (KARAPETOFF), CLEVELAND, OHIO, JUNE 30, 1916. (See PROCEEDINGS for May, 1916).

(Subject to final revision for the Transactions.)

J. B. Whitehead: There is truth in what Prof. Karapetoff has to say about the products of research from Germany and England. I do not know that it is quite as definite as he would imply, but I have in mind the character and form of the publication of the results of research as given in the German and English periodicals; and the publications of the German and English engineering societies, I think are superior to those of our own. I would make a plea here for a more careful editing of the publications of our American research. Certainly a comparison, particularly of the German publications, with our own will, I think, indicate that there is truth in what I say, namely, that these publications are better prepared. The precautions that are taken in experimental work are better described, and more effort is made, and I suppose more careful editing accompanies the publication of the results of experiments abroad.

As regards the special fields of investigation in different universities and colleges as related to their particular equipment, I do not believe that is a practical suggestion. I think that research is a question of men and minds, more than it is of equipment and location. I do, however, believe that continuation of a particular subject that has once been started is a most prolific and valuable principle to have in mind. It is one, fortunately, which results naturally in the course of events—when a particular line of research develops and a mature student or a professor is conducting research, it is most natural that he should invoke the assistance of the younger men, and the younger men's interest is at once attracted, and so the work continues naturally. This condition obtains in many places now.

I believe that the suggestion of prizes for investigations is a very good one. We have a number of prizes in this country now for conspicuously valuable results of research, but they are, I think, usually given as rewards for completed efforts, for more mature work. I believe the offering of prizes for work done by young men, perhaps before they leave college, would be a very valuable incentive.

The suggestion of a Research Committee is not a new one. I had in my hand before I left my office, and expected to bring with me, a small pink leaflet that perhaps some of those present will remember. It was headed "Committee on Cooperative Research," and I think the date was 1903 or 1904. That leaflet sets forth a number of subjects from which in the minds of the Committee profitable results might be obtained. I was interested to find that a number of the subjects which were suggested in that comparatively short list are still to be found in Prof. Karapetoff's list.

I do not think that the list of subjects, such as given by Prof. Karapetoff, goes very far in helping the investigator on his way.

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Fields for study and for investigation are not difficult to point out. I have found in my relation to this subject that it is far more important, not only to suggest the subject, but to outline the attack. It is almost always indispensable that this should be done. Obviously, an investigation cannot be attacked in any direction without a complete survey of the literature and the work which has already been done. It is not possible, however, to entrust to a young investigator a study of the literature and to leave him to work out the lines of his attack. You can point out the literature to a student and tell him where to go so that he can make a survey of the whole field, but even then he cannot digest it. His judgment is not sufficiently matured to enable him to decide which are the contributions most valuable to the particular line of attack he has in mind. I have found much to my discomfort that it is the duty of one who is attempting to inspire research work to go much further than to simply suggest the subject. It is almost invariably a case of outlining the apparatus and the equipment, and generally also ordering it.

Alan E. Flowers: I think a great many colleges have made use of lists of thesis subjects, such as are submitted here, possibly not so long, possibly more varied in some cases. Such a list has very generally been found to be very useful as a starting point, and nothing that I say later should be construed as opposed to the idea of having such lists, but it is certainly true, as Prof. Whitehead has just said, that the most important thing is, that the list should be supplemented by personal interview and by a considerable amount of suggestion and in some cases of instruction.

I am also very much interested in the idea which is advanced in the paper, of giving prizes for research work. It has always been a matter of great regret to me that the original plan for the Edison Medal was not so arranged that the medal would be made available, in some measure at least, for worthy undergraduate theses. As I remember the conditions, there was a certain age limit, and in addition it was provided that the thesis should be entirely the work of one man. In nine theses out of ten, the thesis is the product of two workers. There are several reasons for this. One of them is the necessity in a great many cases, particularly the case of experimental theses, for two observers, and as it is out of the question for a student to hire his observer, he must have a co-worker. This provision eliminated most of the theses of any value.

I think the conditions for such prizes could readily be changed so as to greatly stimulate experimental research work in the case of the undergraduate, and I rather think that there is some need for such stimulation, because the student who conducts an experimental research thesis is greatly handicapping himself as compared with the student who conducts almost any other type of thesis. He is very sure to put in more time on the work; he is very sure to have more worry; and he is very unsure to get re-

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sults that will satisfy anybody. Anything within reason that can be done to encourage and help the experimental thesis is, in my opinion, worth while doing.

I am quite sure that, however much I would object to an educational committee or a research committee defining what subjects certain places should take, there is a great good to be obtained by getting major lines started at particular places and endeavoring to make it possible to continue that line of work at that place.

The reason I object to the scheme of fastening research subjects on places, is that I believe the most important thing is to keep the door wide open for a large number of individual suggestions. Whenever we begin to use the fixed method, what might be called the autocratic method, it seems to me we are killing off the most valuable and the most useful of the possibilities, that is, the origination of ideas, the origination of subjects, the carrying on of individual work and the encouragement of originality.

Scholarships would help, to a certain extent and possibly the most useful thing would be something in the nature of industrial scholarships, made available, not for the undergraduate, but for the graduate student. The undergraduate student who shows ability in research and has originality, would be encouraged by the prize and he might then very easily be led on to the postgraduate work of great value.

I think that great good might come to the Institute from a Research Committee. I am a member of the Research Committee of the American Society of Mechanical Engineers, and I have been very greatly impressed by the possibilities of that committees' work.

I feel it would be hardly right, however, to leave this subject without saying one more word about "prizes" I mean by that, compensation. I am afraid that at the present time there has come into existence the idea that in research "virtue is its own reward." So far as I can see, the relations between compensation in research work and compensations for other kinds of work is very much to the detriment of the research worker, whether he be working in pure science or applied science. That seems to me a fundamentally wrong condition, and I think it ought not to pass unnoticed. It is not only a question of the right of the thing, but also a question of the amount of work that might be done. It is a question of the encouragement of additional work. I have long had the feeling that there ought to be some special form of compensation, besides whatever there may be in the way of salary, whatever there may be in the way of reputation, that will come to the worker for each particular thing which he brings out. I see no reason why, a research worker, who reaches results of value, and allows them to be put on the market, should not get royalties, should not have the sort of thing granted an independent invention.

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The large companies ought to give serious consideration to granting some special royalty or lump payment for each invention developed by one of their workers.

C. E. Skinner: My attitude toward this subject is probably quite different from that of the man in the university, as my whole experience has been in connection with a large corporation. I have many times been asked by university men to suggest subjects for research work. I find it a very difficult thing to do, because it is hard to outline the surrounding conditions to the man undertaking the research. One does not always know the facilities at his command, and the large corporation is, as we all know, whether you are inside or outside, somewhat jealous of the information leading to new things.

I think that some of the cautions, some of the advice, given by Prof. Karapetoff are very good indeed, and I am not sure that some of his subjects, shown in the list, are not too large. I frequently tell my associates that no matter what a subject is, no matter how small it seems to be, if one goes into it completely—going into literature the first, which should always be done, going into the investigation with a view to finding out about all that can be found out about a particular thing—the subject will grow and the interest will grow.

It very often happens that the by-product of the research is of far greater value than the direct result. A research may be entirely successful when it proves that the object sought cannot be attained. It is very hard for young men, particularly, to get that viewpoint, that the proof that a certain thing cannot be done in the way he had an idea it could be done is of as much value, perhaps, as the doing of the thing he sought. It practically always transpires that in the case of doing research of that kind there are some by-products which are extremely valuable and make very good leads for further research. Having that in mind the suggestion of continuous work on a subject when once undertaken is very good.

I have been very much interested in the last year with the attempts of some of the British people in endeavoring to match up, if possible, with the German research. This war has brought home to the English, as nothing else could possibly do, the desirability of working in advance of anything they have hitherto done. I think that ought to come to us in America in the same way. We have had a stimulus here in the enormous orders for material, and we have had a stimulus in the cutting off of many materials which before the war were available, and research in industrial lines is going along at a very rapid rate. The English people feel that on account of their having a very large number of relatively small corporations, that it may not be possible for any one of these corporations to carry on the work in an entirely satisfactory way. Consequently, they are talking of a co-operative research arrangement which would take in the industrial corporation, the university, and whoever else

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might be interested. There is a germ of thought there for us, that some sort of co-operation is desirable.

It is not easy for the industrial corporations to line up on this matter of research, on account of the fact that most industrial corporations in this country depend for their business on the protection given by patents. Patent protection, as we all know, is a difficult enough matter as it now stands, without having the added difficulty of the suggestion proposed, that is, the research being made by the corporation, and then the idea developed patented by some one outside, with no control by the corporation resulting. If our business is founded on patent protection, then we must have control, and while the work of the university can be of great assistance, it is difficult to tie that up in a satisfactory way with the control that must be had by the industrial corporation.

I have stated on a number of occasions, that it was a shame to have the equipment which is possessed by many of the universities, idle three hundred and sixty out of the three hundred and sixty-five days of the year, when many companies would have been glad, if they could get possession of that equipment, to use it three hundred days in the year and make it efficient. It is too much like the farm machinery which is used, for, let us say, one week of the year, and the rest of the year it stands out in the weather. There is any quantity of such equipment in the technical universities of the country which ought to be efficiently used and used throughout the greater part of the year.

Just what arrangement can be made for accomplishing this desirable result of cooperation between the corporation, which must use the results, and the individual research worker, either undergraduate or post-graduate, I am not sure. I have worked out a few individual cases, but more with a view of training research men than any hope that the work in the school would be very productive, so far as actual researches were concerned. As a training for research men, it has proven very valuable.

F. C. Caldwell: It does seem that some kind of co-operation between the various engineering colleges where thesis work, both undergraduate and graduate, is being done, would be very desirable. We must all feel the lack of effectiveness that we experience in connection with much of this work. Along the line of what Mr. Skinner has said, we have to remember that the primary object of undergraduate research, is not the production of valuable results, but the training of men, who are largely beginners, so far as this kind of work is concerned.

What is needed is some kind of clearing house between the various institutions to help in avoiding unnecessary duplication of work. In some cases, especially with undergraduate work, recognized duplication is a good thing, on account of the checking of the results obtained. This also would be facilitated by such an arrangement.

One other point is perhaps suggested in one of Professor

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Karapetoff's items, the desirability of selection of the men who are to do undergraduate research. We try to guide men who seem to have no talent for investigation, and no very great interest in it, into other kinds of thesis work. We give them a design or a compilation, and thus reserve the energy of the instructing force and the equipment for the few men who seem to give promise of really accomplishing something in the way of research and of really gaining something by the training which their work along this line will give them.

E. E. F. Creighton: I think the most valuable suggestions regarding research work were given by our President in his address at the opening of the Convention a few days ago. This whole question, especially the educational side, is of the utmost importance. There is not the slightest possibility at the present time that we can have too much research taught. More theses should be written, beginning with a student's freshman year. Progress is dependent mostly upon research and invention. The idea seems to have gone around that the inventor has an especially fine mind, that he was born clever. I think it is a misconception. There are degrees of ability shown in lawyers, mechanics, doctors, engineers, inventors, and so on. It is not a question of relative ability in these several activities, but training. Research and invention come from the suitable concomitant attitude of mind or view-point. Invention can be taught as readily and as certain of results as any of the professions. A definite course of educational work could be laid out, I believe, which would produce inventors by thousands. Most of the training in life, from infancy, is opposed to the production of inventors. It is too much to discuss at this time but, briefly put, I believe inventors would appear in numbers if everybody would give the mental attention they now apply to "What will people think of me if I do?" to "What will nature do for me if I do?"

To show the results of the attitude of mind I wish to draw a contrast. In a big organization they have their work divided into many different departments. Two of these are Sales Department and Invention or Research Department. The attitude of the mind of a salesman is such that he could not possibly invent. The attitude of mind of the inventor is such that he makes an extremely poor salesman. The salesman must always look to the attractive points, the advantageous points of the things he has to sell. These are known colloquially as the "talking points." He must so impress the purchaser. On the other hand, the research man or inventor must skim over the things that go right and he must worry himself night and day about the little things that go wrong. Start an inventor out in the sales business, and he will tell the prospective customer all the things that are wrong about the apparatus rather then the things that go right.

Before the war started, we had an organization of advanced students in industrial work, and it fell to my lot to take these students, who were all graduates of colleges, for two, three, or

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six months and use them in the laboratory. I have had many illuminating experiences. I got far enough in this work to be able to tell, with a fair degree of certainty, where a man came from simply by watching how he went at his work. One illustration—three men were independently given a problem, and I was unable to see them again for two days. The first man went to the University library where he combed the shelves for information on the subject. It happened to be an investigation of a new type of protective apparatus. He reported that he was sorry that he was away from the big libraries where he could consult the authorities. (Incidently there were no authorities on this subject.) The second man was of a mathematical turn, and he sat down with a pencil and got his fundamental equation started, and attempted to solve the problem by differential equations. He had landed at the point where he had an expression that he could not solve. The third man did not think about looking up published material, and tried no mathematics, but he went into the shop and commenced to make up a device to try out.

Now, of these three men, the first one was educated in Paris, and like the French, venerated the authorities in science. That was his view-point. The second man was educated in one of our best eastern colleges, where they do a great deal of still thinking and a great deal of mathematical work, and although his tastes, as I found subsequently, were such as to allow him to do experimental work, he had been trained to immobile thinking. The third man was from the good old wooly West where they have not formed the habit of looking up the subject or referring to some authority. It seems to me that "try it" is the fundamental need in all research work.

Some time ago I had the pleasure of giving some young men a chance to train themselves for invention. To help me prove my point, I found that as soon as they got the view-point of the inventor they could invent on short notice. I remember one instance, where two of them made three inventions in ten minutes. All of these inventions did not ripen into patents, but, nevertheless, they caught the view point and invented.

We often hear discouraging remarks made to young investigators stating that they are beginning to investigate before they have had any training. It is a great mistake to assume that one must be familiar with current scientific facts before beginning to investigate independently—very much book knowledge is liable to be an overwhelming handicap and a damper to one's enthusiasm. The kindergarten is the place to begin investigation and invention. The work of Mari Montesorri is one of the best illustrations of this theory. If her methods could be carried along through the grammar schools and the colleges the scientific world would move forward in leaps and bounds.

In the university world I know of one professor who, I think, has the proper view-point for training investigators. Professor

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Sanford of Stanford University started his work, and is still carrying it on, in the face of a great deal of opposition. In his course in physics he took away the books from the students and gave them a lot of simple apparatus to work with and set them at it. The criticisms of his methods, especially by the engineering students, were—I can characterize them in one expression—"If I were a Faraday, I could get something out of that course." That is a great mistake. Every investigator must have a start. I have been surprised at the young fellows who have worked with me, who have made an investigation, gathered their data, and then not knowing what to do with it, have gone to some book to find out what it might mean.

As a last proof that my theory is correct, I will cite the case of the Italian janitor in our laboratory, whom I set to work on research work. He has embarrassing moments with his arithmetic and spelling but nimble fingers and an active mind are gathering in much useful data.

D. D. Ewing: It seems to me the trend of the discussion has been mostly along the line of invention. I think that there is a great deal of research work that can be carried on in a university, that does not have anything to do with invention. Research work on subjects like the one which forms the basis of the paper following this one, "Tractive Resistances to a Motor Delivery Wagon on Different Roads and at Different Speeds," is a fair example of what I have in mind. Traffic studies relating to the transportation of passengers, the delivery of freight, the relation of traffic to schedules and car routing, and great variety of other engineering economic subjects are fruitful lines of research, the work on which can be carried on in universities as well as anywhere else. We should not get it into our heads that the only kind of research work is the research work which leads to invention.

Regarding the alignment of research work in universities and colleges, I think that that depends on whether the research work is being done for the purpose of pure research and the results which come from such research, or whether it is being done for the purpose of training young men.

I object to spoon-feeding the students. Too much alignment and guidance are not good for the student. The primary function of the university, in my opinion, is to train men and not to get definite results in research work. Such results, however, as we do get I think should be recorded where they may be available to all, and that, to me, is the crux of Prof. Karapetoff's paper. I desire to say a word regarding another line of research mentioned in Prof. Karapetoff's paper, namely, that of library researches. Such work, I believe, can be carried on in the university to better advantage than in the factories of manufacturing companies, or by engineers, or by the research men of operating companies, because of the library facilities that are available to university men. I think that one of our great difficulties, at least at Purdue

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University, is to get men to do library research. The students all want to do experimental research. Prof. Flowers indicated that he had some difficulty the other way. I feel, however, there is a great field for university research along that line. As has been pointed out in the paper a resume of the various lines of thought and scientific endeavor would be very useful, and this could be carried on by the universities.

Practicing engineers could co-operate in a very helpful manner with the university research men in the suggestion of subjects which are along economic or other lines not leading to invention. I readily appreciate Dr. Skinner's statement regarding the matter of invention. I can see why the manufacturing companies would not care to have such research carried on in the universities, but, on the other hand, all those researches which do not lead to invention could be carried on in co-operation with operating companies, and I think a great deal of value would result from it. Further the research work in this country would be greatly stimulated if we had a little better cooperation between the parties interested in such work.

C. Francis Harding: I wish to bring up one or two points concerning which I am, to some extent, in opposition to the author of the paper, particularly with regard to the question of prizes. I do not believe that a monetary prize or any other prize is going to develop research men or induce them to take up research investigations in the university. I think possibly that some prestige, some honor, which might be conferred on such a man, possibly some recognition by the Institute such as the publishing of the paper, or that which the Engineering Society of Western Pennsylvania offers in connection with its thesis investigations would be far preferable to holding out a prize of $25 or $50, whatever it might be, for the man who would carry on the best research investigation. The latter would take on the form which the university degree assumes for such men who are working to get the sheepskin only, and not for the training which the sheepskin represents.

I do not believe, to take up another question treated in the paper, that it is necessary for the Institute or any other body to suggest subjects. Any live man who is connected with a university, talking half an hour with an engineer of a manufacturing company, or of a public utility corporation, can find readily a large number of subjects which are available and worthy of research investigation, and which his institution is best fitted to undertake. Such may have either a practical bearing, or possibly some value as an invention.

I feel that any action which the Institute may be able to take such as appointing a Research Committee or along any other line which will lead towards further co-operation between the universities and the men of the manufacturing companies and the utilities interested in research, will be to the mutual advantage of the student, the universities and ultimately we hope, to the manufacturing companies and the Institute as well.

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N. S. Diamant: We may disagree with Prof. Karapetoff as to specific suggestions made in the paper, but I think we shall all agree that it is high time that universities raise their standards of *scholarship* and *research* and do their share along with the industrial corporations. It may not be exaggerating the importance of the subject to say that it will prove a national calamity if they do not.

Research is not something as mechanical as a glance at the paper may suggest, and in regard to it we may well refer to President Carty's address and abide by his advice and some of his suggestions.

The average standard of scholarship and research at present is very low—considering the universities all over the country—and the author seems well justified in using the expression "superficial undergraduate thesis" with emphasis on superficial.

In regard to the quantity and quality of work that has been done so far in the United States and in Europe—as I would add Switzerland, France, Belgium, etc., to the countries mentioned by the author—I am afraid both Mr. Whitehead and Prof. Karapetoff are right in their comparison—the European work in general seems to be more thorough, and to be published in a more *scholarly form*, not only from a *technical* point of view but *literary* as well.

J. J. Carty: The distinction which I made in my paper between pure scientific research and industrial research is a distinction which I think should be borne in mind all of the time in considering questions such as these. I have frequently heard during the discussion here the term "research," employed as though it meant but one thing. It really means two things. There is pure scientific research and industrial scientific research, and the necessity for this distinction is well illustrated when we come to discuss the ethics of publication as applied to the two cases.

Pure scientific research is conducted for the purpose of extending the boundaries of knowledge and publication is one of the goals. It is ethical to publish these results; it would be unethical not to do so.

When it comes to industrial research the ethics of the case are different. The industrial scientist is employed by a manufacturer or other client to make a scientific investigation at his expense and for his benefit. It would be unethical for the industrial scientific research worker to publish the results of his investigation until his client gives him permission to do so; that is, until the client has determined to his own satisfaction that he will not be injured by the publication.

There is no obligation whatever upon the manufacturer to give out to his competitors scientific information obtained at his expense and for his benefit. The manufacturer embodies the results of his scientific investigations in practical form and benefits the public through the improved product which he pro-

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vides. Almost invariably, however, the results of industrial scientific investigation are published in due course, as a rule this publication being in the form of an issued patent, which is the method adopted by our form of government to take the place of trade secrets. I am told, however, that there is such a thing as property in trade secrets and if you will read the remarkable paper by Mr. Frederick P. Fish on "The Ethics of Trade Secrets," you will find there a great deal of interesting and curious information upon this subject.

The question as to whether our universities or technical schools should undertake industrial scient fic research is a large one which is now being carefully studied by many who are interested in the subject. It is certain that if the technical schools are to carry industrial research work to the point of taking problems from the manufacturer and solving them for pay, the manufacturer will insist upon a contract with the university whereby the publication of the results will be forbidden until such time as he is protected by issued patents, or for other reasons concludes that his interests will not suffer by the publication.

I do not wish to imply that there is no place for industrial research in the universities or technical schools. This question is now being seriously studied. I hope it will be found that there will be a great deal that they can do. I hope to see spring up near the universities large industrial research laboratories and if it is found that they can be successfully associated with the universities, all the better.

In any event, as soon as our manufacturers have awakened to the importance of industrial scientific research, I believe industrial laboratories will spring up everywhere and that the universities and technical schools will find it difficult to graduate in sufficient numbers men trained in the rigorous methods of the pure scientist to carry on the work of industrial research.

D. H. Braymer: I was interested in the remark of one of the speakers, comparing American journals with foreign journals. I think I have an explanation. It is hardest to obtain the results of research work from professors and universities themselves. It is next easiest to get it from the manufacturing companies, and it is easiest of all to get it from the research departments of the operating companies. Operating engineers interested in new developments are always glad to tell what they have done, why they have done it, and what they are going to do. I can see no reason why there should not be the same attitude toward a publication on the part of the universities and the manufacturers.

A. A. Nims: We are thinking today in terms of the nation rather than in terms of the individual. Five of the national engineering societies are just completing an important step in the preparedness program upon which the country has entered. It is, therefore, appropriate and significant that we have brought to our attention, as convincingly as Professor Karapetoff has done, another service wherein the same societies, with others, can ren-

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der effective aid in furthering that larger preparedness for national co-operation of which military readiness should be an incidental phase.

Scientific research has not been regarded with that degree of respect by those who might devote their talents to it, nor has such reliance been placed upon it by those who might use its results, as has been accorded it elsewhere. The writer has a distinct recollection of the distaste and dissatisfaction with which senior thesis was regarded at the engineering college from which he graduated. The fellows looked upon thesis work as "not practical," *i. e.* unrelated to the work they expected to take up after graduation, or else themselves unfitted to accomplish results commensurate with the effort expended. Hence the majority of them considered there were other more profitable uses for their time, and since senior thesis has been made elective few take it.

The business firms that are able to maintain adequate equipments for effective research are vastly outnumbered by those who are unable, and who acquire their new technical information by accident or by appealing to some outside agency for the solution of special pressing problems. Occasional, unrelated research, inspired by sporadic inquiries, is more expensive, less effective and commands less confidence than well-organized, well-directed, continued effort. The economics of a high load-factor applies to a plant for scientific research in the same manner, though not to the same degree, that it does to a plant for producing electric energy.

With research encouraged and coordinated throughout the country students would gradually take a different attitude toward their first encounter with such work. Inquiries on various subjects would be referred to the best authority, securing the most reliable information in the shortest time.

It is quite possible that one of the greater and more lasting benefits of the present commercial activity under limited supplies of materials may be found to lie in the fact that it opened our eyes to the incompleteness of our scientific and technical knowledge and compelled us to take systematic means to extend it. It is, therefore, greatly to be hoped that Professor Karapetoff's suggestions may lead to constructive action along the lines pointed out.

Alexander Gray: The technical press is not able to obtain original articles from the universities because the universities are not turning out good stuff. Most of the research that is started is never completed because there is a lack of men of research ability and because the men available are not properly guided. The large corporations take the best of the men and some of those that are left become teachers.

The original work done in most of our schools does not begin to compare with that done by the manufacturing companies and it is not because of lack of equipment. What we need

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rather is men like Kelvin of Glasgow, Thomson of Cambridge and Arnold of Karlsruhe to guide our graduate schools, but such men do not seem to develop in our universities.

One of the speakers considered it inadvisable to offer prizes for research. I have seen how two prizes offered to engineers for public speaking have set a whole senior class to work by giving direction to its thought.

Prof. Karapetoff is right when he insists on the schools limiting themselves to one or two subjects rather than spreading their energy over a large number of disconnected subjects. Only by years of work in a given field can results be obtained that are of great value, and only in this way can the work be carried on from year to year with instructors always coming and going.

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DISCUSSION ON "TRACTIVE RESISTANCES TO A MOTOR DELIVERY WAGON ON DIFFERENT ROADS AND AT DIFFERENT SPEEDS", (KENNELLY-SCHURIG), CLEVELAND, OHIO, JUNE 30, 1916. (SEE PROCEEDINGS FOR JUNE, 1916.)

(Subject to final revision for the Transactions.)

A. A. Nims: (communicated after adjournment): There is one factor of tractive resistance which has not been separated and listed in this paper. Its value may be of small significance and perhaps may not affect the accuracy of the results to any great extent, but its existence should be recognized at least, if for no other present reason than technical accuracy.

The authors of the paper define "road resistance" as "the horizontal force required to pull the truck over the horizontal road" and "air resistance" as "the horizontal force on the truck required to overcome the resistance of the air". Eliminating "wind resistance," the power delivered to the driving wheel treads at constant speed on a level road is considered equal to the sum of the power consumed by road and air resistances. Yet, in calibrating the truck, belt losses on the wheel treads are found to be an appreciable item, especially at the lighter loads.

The driving wheels of any self-propelled vehicle do double duty—they carry a large share of the load and also deliver to the road, by a friction transmission, the power for propelling the vehicle. It would therefore seem logical that, in evaluating "the horizontal force required to pull the truck" the losses of the friction transmission, consisting of driving wheels and road, be considered in addition to those transmission losses that occur entirely within the vehicle mechanism. A simple means of covering all these losses is to make the term "vehicle efficiency" include all losses from the battery terminals to the ground instead of to the wheel treads only. When "vehicle efficiency" has this meaning, it may be used to determine a value of vehicle output which, at constant speed on a level road, is equal to the power required to tow the vehicle under the same conditions.

O. R. Schurig: In the discussion communicated by Mr. Nims, the "vehicle efficiency", (*i.e.*, the efficiency from battery terminals to the ground) is mentioned as being technically more accurate than the "over-all efficiency of driving mechanism", the latter meaning the efficiency between battery terminals and wheel treads, the difference between the two efficiencies being that in the first, the losses in the tire treads are considered as part of the *vehicle losses*; while in the second, they are considered as part of the power delivered by the *vehicle*. In order to group the tire tread losses among the vehicle losses, it would obviously be necessary to separate the former from the losses occurring in the road surface proper. Since an accurate practical method for the separation of these two mutually dependent losses is not known to the authors, the "vehicle efficiency" as defined by Mr. Nims seems to be purely theoretical. If the latter efficiency were practically obtainable, it would seem to be less

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useful than the over-all efficiency employed by the authors, because it would be dependent not only on the truck speed and battery output, but also on the nature of the road surface.

The "over-all efficiency of driving mechanism" as defined and determined in the paper, (1) is believed to be technically accurate, because it takes account of all components of the power originating at the battery terminals; (2) it is readily obtainable experimentally by the procedure outlined in the paper; and (3) it is the term employed in the determinaton of all those portions of the battery output, which are dependent upon the nature of the road surface, *i.e.*, the joint tire-tread and road-surface losses. These joint losses serve as a basis for the calculation of the horizontal force required to move, at constant speed, a truck having ordinary tire losses, but being otherwise frictionless.

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DISCUSSION ON "APPLICATION OF A POLAR FORM OF COMPLEX QUANTITIES TO THE CALCULATION OF A-C. PHENOMENA" (DIAMANT), CLEVELAND, OHIO, JUNE 30, 1916. (SEE PROCEEDINGS FOR JUNE, 1916.)

(Subject to final revision for the Transactions.)

Alexander Gray: Every September, before I meet my classes, I have to review the subject of complex quantities as applied to the solution of the problems in electrical engineering because, during the rest of the year, I never have occasion to use this method in my own work.

I am afraid that, in some of our schools, the use of this method is carried to extremes. An induction motor for example becomes a curly line and is called $r + jx$ but, while the solutions obtained are elegant, the student does not always know what they mean nor does he obtain such an idea of the operation of the machine as to argue regarding its characteristics when away from his formulas.

It is true that in circuit work solutions may more readily be obtained by the use of complex quantities than by other methods but I find that if the problem is not in the book the student is not satisfied with the solution until he has checked it by vector diagrams and trigonometry.

Unfortunately the average student is not equipped with sufficient mathematics to understand what he is doing when he uses the methods of Dr. Steinmetz or this elegant method now suggested by Prof. Diamant.

E. E. F. Creighton: I think it is very exceptional indeed that mathematics is used after leaving college. Men come to me, who have been out of college a year, and are unable to use the mathematics which they learned there. Of course, there are exceptions. I should say this condition is somewhat a reflection on the methods of teaching mathematics. There are a good many things interesting about mathematics, although you would never know it by the way it is taught.

It happens that other methods seem to be favored in the industrial concerns. One can get a solution of a problem in general more quickly and better by some non-mathematical method. I must say, however, I have had several men with me who have been of the greatest help to me by being able to use freely the mathematics favored by Dr. Steinmetz.

May I ask Mr. Diamant just where is a good place to apply this mathematical method?

John B. Whitehead: I want to ask Professor Gray what is his explanation and justification of the original vector diagram. How can he give the vector diagram to a student, without taking it back somewhere to a mathematical expression, and if to a mathematical expression, why not to the polar diagram? I take it that he will agree with me that there is no justification for the crank diagram. Therefore, I think this paper should be of some interest to those of us who have to teach.

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I do not suppose Mr. Diamant will claim that this paper should be used by the work-a-day engineer. In fact I question whether Dr. Steinmetz, although he has taken his own method so far into the range of application, would maintain that to be its end and object. The great debt we owe to Dr. Steinmetz is for having developed a method which is so universally applicable in the teaching of principles. I do not agree that the exponential expression is the proper one for the fundamental instruction, and I think the polar diagram, taking its origin from the exponential expression, and the method of division into two components, is the most valuable. The method of Dr. Steinmetz in the division into two components seems to me to fail at the problem of power expression—the product of two vectors. The present paper offers something to fill this vacancy, and hence merits attention.

E. H. Colpitts: Referring to Professor Gray's question inquiring as to the usefulness of Dr. Steinmetz's mathematics, I feel safe in saying that the telephone engineer at least finds these methods of very substantial value in handling many problems.

N. S. Diamant: I think the general trend of remarks was about complex quantities in general, rather than the particular method given in the paper and showed a little prejudice in connection with the question. Probably this is mainly due to the fact that some persons want to use nothing but complex quantities, while a great many others will have nothing to do with them.

In regard to the question raised as to the usefulness of mathematics I think we must recognize that mathematics in engineering is very useful as a tool. I could give actual examples where great advance has been made by the use of mathematics, and very wonderful scientific and practical work has been produced by the use of it. After all, as I say, I am not here to defend mathematics. I think the trouble comes in when we use too much, or try to cover up our ignorance by the use of mathematics, and that is done quite often; you will find it in many so-called text-books.

E. E. F. Creighton: I asked what your particular method of mathematics is, how you could apply it, in what particular way could you apply it.

N. S. Diamant: I have indicated that in the summary of the paper. However, as it has been brought out by Prof. Gray —the choice of method depends considerably upon the type of mind. Some persons like one method, and some persons like another; one is just as good as the other.

Another point of interest that Prof. Gray brought up was that the student, when he is working with complex quantities, is not entirely satisfied, and does not well understand the problem until he has translated it graphically by means of a vector diagram. In that connection I would like to add that the advantage of my method is that it is a better mathematical

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shorthand by means of which to visualize vector relationships. This is not easy to do in complicated vector diagrams, when you have to deal with the components; when for example, we have $e + je$ equal to E, or similar expressions. It is easier to visualize the different phase relationships if the method described in the paper be used, rather than the ordinary method. For example, in a certain case, one hundred volts, making 45 deg, with the horizontal axis will be represented as 141 $j^{\frac{1}{4}}$, instead of 100 $+ j$ 100.

The question was brought up by Dr. Whitehead in regard to double frequency quantities. Really, that does not come entirely within the scope of this paper. I would like to take that up in detail with Prof. Whitehead, but here I may say that personally I think that double frequency is an unnecessary complication. It was introduced by someone who was interested in it, and I think it leads into rather unscientific inconsistencies, and I do not think it has any importance.

John B. Whitehead: Perhaps I have used an unfortunate expression in the words "double frequency". Certainly I have not made myself understood by Mr. Diamant. I simply refer to the fact that it was not meant to include what is usually called the double frequency quantity, which is treated by Mr. Diamant, at some length.

N. S. Diamant: In answering I may say that some persons start with vector quantities, and use these exclusively and suppress the use of instantaneous values. But the scientific definition of power is the one given in the paper involving instantaneous values, where the mean power is obtained by integrating or summing up the instantaneous power over a half cycle. This does not lead into the difficulties of changing the sign, and dropping out the imaginary portion of the product into which one is led when he uses vectors entirely. This vector definition of power leads into what we might consider a quaternion, that is, a quantity made up of scalar and vector components; but power itself is a scalar quantity, since it is absolutely fixed when the magnitude is given, and it is not necessary to give additional information as to the direction of the quantity. The double frequency idea is designed to get around this difficulty, and in a way gives physical explanation of it, but I think it is unnecessary, and a round-about step to take.

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REPORT OF COMMITTEE ON PROTECTIVE APPARATUS

Summary of the Work of the Committee

BY E. E. F. CREIGHTON, CHAIRMAN.

The committee met formally three times during the year. The activities of the committee might be divided into five categories.

1. An endeavor to standardize lightning arresters and similar protective devices.

2. A discussion of the factors involved in attempting to standardize the rating of oil switches.

3. An analysis of the protective problems connected with relays, split conductor cables, and like protective means.

4. A collection of data on partially solved problems relating to protective devices and continuity of service in the transmission of electrical energy.

5. Presentation of data and information in the form of papers, as follows:

Four papers on operating experiences with protective devices, three papers on the pressing problems relating to line insulators, and one paper on the theory of parallel grounded wires. These eight papers are listed below:

Studies in Lightning Protection on 4000-*Volt Circuits*, by D. W. Roper.

Protection of High-Voltage Distribution Systems by Isolating Transformers, by O. O. Rider.

Operating Experience with Protective Devices, by N. L. Pollard and J. T. Lawson.

Protection of High-Voltage Telephone Lines, by E. P. Peck.

Tests on Insulators on the Line and in the Laboratory, by F. L. Hunt.

Experiences in Testing Porcelain, by E. E. F. Creighton.

Graduation of Capacitance of Suspension Disk Insulators in Series, by R. H. Marvin.

Theory of Parallel Grounded Wires and Production of High Frequency in Transmission Lines, by E. E. F. Creighton.

Besides the papers listed above there have been a great many data contributed by members of the committee which could not be coordinated and edited in time for this year's report. There was also submitted to the chairman a paper on power reactances by Mr. J. A. Johnson. There were also two papers promised on "The Rating of Oil Switches" which did not materialize although most of the data of one of these were presented to the committee and discussed.

It is customary for the chairman of a committee to do most of the work of the committee. This particular committee is an exception as will be noted by the amount of valuable published material by members of the committee, also by undigested material not yet edited. There is much still

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to be done in the desirable endeavor to bring a semblance of order out of the chaos of variable practises and unsolved problems relating to the protection of electrical circuits.

The appointment of committeemen should be made especially on the basis of their willingness to undertake active part in the proceedings of the committee. While it is desirable to have certain members of the committee who give their broad experience in a consulting capacity, yet with the large amount of work still to be done, if any great degree of progress is to be made in the coming year, it calls for the united effort of a number of active engineers.

The first section of the committee's report dealing with lightning arresters follows.

Report of Committee

Lightning Arresters And Allied Protection

In endeavoring to standardize lightning arresters and other closely related protective apparatus it is recognized that the functions are not as currently understood as other apparatus such as generators, transformers, motors, etc. It therefore seems necessary first to enumerate the abnormalities on the line; second, to note the nature of these troubles; third, to name the available apparatus to give protection; and fourth, to define the characteristics of the protective apparatus.

The object of this report is to endeavor to place information before the engineer such as will form a basis for comparing different types of lightning arresters and other protective apparatus which are available on the market today. Improvements and changes are being made from time to time. Some factors in lightning arrester designs will be magnified at the expense of others and it is therefore desirable to be able to form a judgment on the relative values of arresters for different kinds of service.

In the subject of protection, the first five great divisions of the conditions to be avoided in the circuit are:

A. Abnormally high voltages.

B. Abnormally high frequencies.

C. Abnormally high currents.

D. Troubles other than electrical troubles to apparatus.

E. Outside interferences.

A. As a matter of convenience the following subdivisions can be made of *abnormally high voltages:*

1. A few transient shocks such as will be obtained from lightning, switching, etc.

2. Many successive transient shocks such as come from an arcing ground.

3. Permanent high voltage such as will come from a cross of one circuit with another of high impressed potential.

B. Subdivisions of high frequency. From one point of view an abnormally high frequency falls in the subdivision of abnormally high potentials since, in general, it is only the high potential caused by the high frequency that can do harm to the insulation. High frequencies, however, are not always initially of abnormally high potentials but even at low potentials these high-frequency surges may be transformed and concentrated in the circuit in such a way as to cause local damage. There are

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two common conditions where high frequencies, which are comparable in voltage to the normal voltage of the circuit, may cause harm. The first of these is when a traveling wave enters a coil and by the retardation of the inductance piles up potential on the end turns. The second of these is by the frequency of the surge coinciding with the natural frequency of some local combination of inductance and capacitance which thereby causes a resonant rise in voltage by a concentration of the surge energy in this particular locality of the circuit. Finally it should be noted that there is a single impulse which is not in itself an oscillation but can give the effects of an oscillation by the suddenness of the rise of current or, as usually expressed, by the steepness of its wave front.

C. The following subdivisions may be made of ***abnormally high currents:***

1. Dangerous overloads on apparatus.
2. Short circuits of parts of apparatus.
3. Short circuits across the main lines.

Protection In General Against The Above Abnormalities

Up to the present time there have been developed in the electrical field the following devices to protect against these abnormal conditions:

For transient high voltages there are lightning arresters.

For arcing grounds, arcing ground suppressors.

For permanent crosses, various fuses, circuit-breakers, and relays but no well defined practise in many lines other than careful mechanical construction at the crossing points of transmission circuits.

Against abnormally high frequencies there are high-frequency absorbers as protectors.

Against abnormally high currents there are, first of all, automatic circuit breakers, automatic switches, and fuses in combination with actuating relays, duplicate circuits, etc.; second, short circuit suppressors.

As an alleviating device against the damaging effects of abnormally high currents of short circuit, there are power reactors which may be located in several positions in the circuit.

(A and B) Further Details on Apparatus
Definitions of Lightning Arresters and Absorbers

There is needed distinguishing definitions for devices which operate by abnormally high potentials and others which operate by high frequencies.

A ***lightning arrester*** may be defined as a protective device which comes into operation due to the presence of high voltages of transient nature and relieves the surge of its energy by the passage of current by conduction and yet, in its normal operation, does not interrupt the service of electric power.

A ***high frequency absorber*** is a protective device which comes into operation due to the presence of high frequencies regardless of the voltage of those high frequencies relative to the line voltage, and relieves the surge of its energy by the passage of current through a resistance.

Further Comparative Statements. Although there is an overlapping of the functions of these devices they stand distinct at the extremes of clas-

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sifications. At one extreme is the arrester with its series gap coming into operation only for abnormally high voltages and at the other extreme the high-frequency absorber coming into operation mainly by high frequencies and steep wave fronts, regardless of potentials. There are lightning arresters in use without series gaps and some of these perform the double function of arrester and high-frequency absorber. Since most of the dangerous surges are of high frequency or steep wave front, the absorber in absorbing these surges may function also as a lightning arrester. Yet the high-frequency absorber functions in an important way when the arrester fails to discharge and therefore the distinguishing mark is needed.

Characteristics of Lightning Arresters

In selecting lightning arresters there are at least four main characteristics which must be considered:

a. Protective qualities.

b. Durability.

c. Disturbances in the circuit caused by the reaction of the discharge of the arrester.

d. Cost.

Characteristic a. Under protective qualities must be found the answer to the question—Will the arrester prevent dangerous rises of transient potentials? To answer this question three factors at least must be considered, namely:

(1) Its spark potential, both initial and at every instant of its operation.

(2) Its discharge rate, expressed in amperes, at an impressed potential of double the normal voltage of the circuit.

(3) Its dielectric spark lag, which is determined by taking its equivalent sphere gap under various conditions of impressed potential, frequency, wave front, etc.

Characteristic b. Under the characteristic of durability the question to be answered is: Will the arrester itself be injured by the service conditions? The answer to this question is found by determining:

1. Its ability to withstand the heaviest discharges in service.
2. Its ability to withstand successive discharges.
3. A study of its possible decrease in discharge rate due to deterioration.

Characteristic c. The disturbances caused by the operation of an arrester may be classified as high frequencies and abnormally high currents. Arresters with an internal capacitance may cause a high-frequency disturbance when they discharge unless the energy of those disturbances is absorbed. Arresters which take a heavy current from the generator may cause a drop in voltage on the circuit from the overload and thereby make themselves felt in the currents and speed of synchronous apparatus by winking of lamps and by decrease in speed of loaded asynchronous motors.

There is a marked tendency among engineers to distinguish between *lightning arresters* and *high voltage relief gaps*, the name of arrester being reserved for those devices which normally function without causing interruptions of service. In the relief gap there is no characteristic that will stop the flow of the energy from the generator without putting the

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gap itself out of service. Otherwise expressed, a relief gap opens the circuit by blowing its own fuse or by opening the main circuit-breaker or by causing the operation of some other protective device such as a short-circuit suppressor.

Characteristic d. The cost of an arrester should, as an engineering proposition, be compatible both with the revenue from the sale of power and the value of continuity of service. Due to the fact that a failure of an arrester may cause a general interruption on a circuit a cheap arrester must be examined with extra care from the standpoint of durablilty.

E. E. F. Creighton, Chairman,

H. H. Dewey,	E. B. Merriam,
Louis Elliott,	L. C. Nicholson,
V. H. Greisser,	N. L. Pollard,
F. W. Harris,	E. P. Peck,
S. Q. Hayes,	O. O. Rider,
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THE EFFECT OF RECENT DECISIONS ON THE WORK OF INVENTORY AND APPRAISAL

BY PHILANDER BETTS

ABSTRACT OF PAPER

In order that our inventories and appraisals shall be useful in determining all of the appropriate elements of value, they must be classified as to age, condition, use, and extent of use in each class of service.

DURING the past few years there has been much discussion on the proper basis for rates. This discussion has been quite confusing at times because of the entrance into it of those who were not familiar with all sides of the question. That is, engineers not familiar with the existing legal decisions have argued pro and con on the subjects of valuation and depreciation, and lawyers not familiar with development cost have based their arguments entirely on the decisions of the Courts.

If we are to have proper respect for our Courts, we must abide by their decisions and, if not satisfied, we must familiarize ourselves with all of the conditions leading to the Courts' decisions. Probably the earliest cases which begin the history of decisions concerning valuation are those of the Brunswick and Waterville, Maine, cases. We must bear in mind, however, that those were cases in which negotiations were in progress looking to the sale by water companies of their properties to the municipalities. In those cases the franchise rights had either expired or the municipalities had the right to take over the properties as well as the franchises, and thereafter operate them. In "purchase and sale" cases, clearly the matter to be determined is the *value* of the property, all things considered, including "going concern" values if any exist. After a study of many of the great rate cases, the writer has come to the conclusion that the confusion of mind has come from the fact that the early decisions were based upon "purchase and sale" cases and did not primarily have anything to do with cost in its broad sense.

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Value not Cost

If we are, however, to do our work in conformity with the Courts' decisions, we must take as our primary basis for the consideration of rates, the value of the property and not necessarily the cost. Justice Harlan was wiser than he knew when, in the famous case of Smyth v. Ames, he said as follows:

> We hold, however, that the basis of all calculations as to the reasonableness of rates * * * * * must be fair the value of the property being used by it for the convenience of the public. And in order to ascertain that value, the original cost of construction, the amount expended in permanent improvements, the amount and market value of its bonds and stock, the present as compared with the original cost of construction, the probable earning capacity of the property under particular rates prescribed by statute and the sum required to meet operating expenses, are all matters for consideration and are to be given such weight as may be just and right in each case. We do not say there *may not be other matters* to be regarded in estimating the value of the property. What the company is entitled to ask is a fair return upon the value of that which it employs for the public convenience. On the other hand, what the public is entitled to demand is that no more be exacted from it * * * * * than the services rendered by it are reasonably worth."

Reproduction Value v. Original Value

The general trend of recent decisions has been to make reproduction cost the sole or controlling basis of value for rate purposes. Some Courts plainly state that, in their opinion, actual cost, capitalization and other factors are to be considered only to the extent that they may throw light on the cost of reproduction or existing depreciation. In support of this principle, the opinions of the Supreme Court of the United States, indicate that it is the "present value" of the property that is to be determined; thus, in Smyth v. Ames, reference is made to "the fair value of the property being used * * * * * for the convenience of the public"; in San Diego Land and Town Company v. National City, it is "present value"; in the same case, on appeal to the Supreme Court, Justice Harlan refers to "reasonable value of the property at the time it is being used for the public"; this is quoted as settled law by Justice Holmes in 1903, and by Justice Peckham in 1909 in Wilcox v. Consolidated Gas Company. It is argued that this constant use of the present tense by the Supreme Court in referring to fair value for rate purposes must at once exclude actual cost or original cost from having any controlling influence in the determination of fair value. Under this interpretation

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present value must be based either on market value or reproduction cost, and as market value is not usually considered a fair or possible standard for rate purposes, reproduction cost is turned to as the only available standard. This line of argument would be more convincing were it not for the fact that in the leading case of Smyth v. Ames in which the present value principle is laid down, it is also distinctly stated that both original cost and reproduction cost shall be considered in determining a fair present value, and it is no indication that either of these factors should be given a controlling influence. This cannot be accepted as the settled rule of law as the whole subject of valuation is still in a developmental stage. The Supreme Court of the United States has wisely refrained from laying down a hard and fast rule which might have to be reversed when all of the factors of the problem shall have been more clearly discussed.

Value New v. Depreciated Value

In the so-called Idaho case, it has been determined by the Court that the value new of the property is the proper basis for computation of rates rather than a "present value" obtained by deducting the full estimated depreciation. This decision follows a number of commission decisions along the same general line and is best expressed in the words of the St. Louis Public Service Commission in the case of the Union Electric Light and Power Company of St. Louis, decided in 1911, "In depreciating, to arrive at the present value, the Commission does not consider it fair to make deductions for anything but the present physical condition and for items where it is plainly apparent that the property has become obsolete and inadequate."

Property Used and Useful

From the earliest cases down to the present time, the Courts have been unanimous in the determination that the basis for rates must be the value of the "property used and useful" and have not been very definite in further defining these terms. The Commissions have, however, in a number of cases, after determining the value of the entire property, made deductions for property considerably in excess of that required for the present * customers or those who might be taken on in the near

*San Diego Land & Town Co. v. National City.
Long Branch vs. Tintern Manor Water Co.
Mantua vs. New Jersey Gas Co.

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future. This has sometimes occurred, and occurred recently in New Jersey, where companies have been too optimistic with regard to the development of the territory and have built plants far in excess of the actual needs. It also follows from this, that rates may not be based upon an inadequate plant but that the valuation to be determined will be that of a plant adequate in all respects for the customers now connected and including a reasonable reserve for customers who may be taken on in the near future, as well as reserve to guard against the ordinary break downs and interruptions in service.

Classification as to Use

The next decisions of interest affecting our work of inventory and appraisal are those of the Norfolk and Western Railroad Company v. Conley, et al, and the Northern Pacific Railroad v. the State of North Dakota. The effect of these decisions is to require different rates for classes of service where the costs are greatly different. The basis for differential rates is found in one of the earliest Supreme Court decisions in which it was held that "what the company was entitled to was a fair return upon the value of that which it devoted to the public use" but the Court went on to say that what the purchaser was entitled to was "service at no more than the worth to him." This decision practically confirmed the railroads in their existing practises of having different rates for different classes of service. With regard to electric lighting and power companies, it has been customary to classify customers in accordance with their requirements for service. This classification, however, was based on and adhered more or less closely to the cost for the respective classes of service.

Result

The result of the above mentioned decisions is that the inventories and the resulting appraisals must be classified in accordance with the use and the extent of the use. So far as the engineer is primarily concerned with cost, the inventory and appraisal will arrive at the same aggregate in any case, but the engineer is further concerned with the use and operation of the electrical property and it is the duty of the engineer to determine to what extent each class of property is required in the service of the public and to what extent it is required for the furnishing of the various classes of service. In preparing our inventory, therefore, such classifications must be made as will

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readily show the use to which the property is devoted. In the determination of rates it becomes especially important when it is recognized that charges for municipal street lighting have almost invariably been lower than the proper proportionate costs for this class of service, and where a company has been reasonably successful in carrying on its business it follows that the rates charged for other classes of service have been too high and the recent Court decisions* forbid the collecting from one class of customers any unreasonable portion of that which ought to be collected from other classes of customers, and further forbids the lowering of rates for reasons of public policy.

As to the calculations for depreciation, while the Idaho decision is to the general effect that full or theoretical depreciation should not be deducted in obtaining the fair value of the property, it cannot be said that this principle is at all well established, and it becomes necessary, in our inventory, to determine the accrued depreciation of each item, taking into account not only ordinary wear and tear, but obsolescence and inadequacy (which some authorities call functional depreciation). The writer has long been of the opinion that in order to square our valuations with the Court decisions, we must (1) obtain definite appraisals of the existing physical property, (2) ascertain the full theoretical depreciation, (3) make such deductions as are necessary because of property built unwisely or for anticipated increases in population which have not materialized or for classes of service which have not been taken on. In other words, our valuation must be determined by using our best present-day judgment as to the amount and classes of property required to serve the customers now connected and those which may be connected within a reasonable future period. This may even involve an addition for property not now in place, but which ought to be in place in order to assure continuity of service with the requirement that same be installed. In addition, however, to the value of the physical property, the writer desires to take refuge behind the words of Justice Harlan when he says, "We do not say that there may not be other matters to be regarded in estimating the value of the property." It is the writer's contention that in making the appraisal of the physical property, due allowance must be made for overhead charges. The writer's opinion on this phase of the matter has already been expressed in a written discussion which appeared at the San Francisco

*See Norfolk & Western & North Dakota cases cited above.

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Convention of the Institute in 1915. In addition, however, there are allowances for various intangibles not properly included under the head of overhead charges. They are (1) cost of organization and obtaining the necessary charters and franchises, (2) deficits in operation in the early history of the project, (3) lack of profits in the later years and (4) the unearned depreciation which has accrued. It is the writer's further opinion that the aggregate of these elements ought to bear some favorable relation to the total value of the physical property but it is the province of the engineer to investigate and determine the various items referred to with the exception, perhaps, of items concerning the cost of organization and obtaining the necessary charters and franchises. All other elements in determining the appraisal and valuation of a public utility property and in the determination of the deficits, lack of profits or otherwise, are matters solely within the province of the engineer.

The above items should be considered as making up the "cost of establishing the business." There has been much contention with reference to the necessity of including "going value" but here again we are confusing cases involving justice to the investor with "purchase and sale" cases. "Going value" is an element to be considered in "purchase and sale" cases and has no pertinency whatever in rate cases. The United States Supreme Court, in its recent decision regarding the Des Moines gas rates, decided that "going value" was to be considered in these cases but based its estimates of "going value" on those elements which go to make up the "cost of establishing the business." In the determination of reasonable or fair rates, full consideration must be given to the sacrifice made by the investor. This will include, in addition to the investment in the physical property, early losses, lack of profits and unearned depreciation, the aggregate of which should be classified as the "cost of establishing the business."

Conclusions

1. Property must be inventoried in such detail as will lead to a determination of its value or cost within a very small percentage of absolute accuracy.

2. It must be classified as to its use and as to the degree of its use in the various classes of service.

3. The inventory must include full information as to age and present condition, this information leading to accurate estimates of accrued depreciation.

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CONTINUOUS INVENTORIES: THEIR PREPARATION AND VALUE

BY HARRY E. CARVER

ABSTRACT OF PAPER

Due to enactment of laws in various states requiring approval of State Commissions before issue of securities, and due to other conditions, there has arisen a demand for a continuous inventory of property owned by utility companies.

First section of this paper discusses the advisability of attempting such an inventory, giving possible uses and advantages to be derived therefrom, and the second section discusses the preparation of such an inventory, suggests the division of the property into four general groups for the purpose, and outlines general forms and methods for collecting and recording data required.

AMONG papers presented at the Pacific Coast Convention of the Institute at San Francisco in 1915, under the general heading of a *Symposium of Inventories and Appraisals of Properties*, was one by Mr. W. G. Vincent, Jr., in which the subject of keeping inventories and appraisals up to date was treated in some detail. In the discussion which ensued, it seemed to be the opinion that the amount of detail and extra work and expense which would be incurred by a company's operating force, would be too great to make it advisable or practicable to do this. At least one of the large public utility companies under the jurisdiction of the New Jersey Commission, namely one of the telephone companies connected with the Bell system, is apparently accomplishing this with an expenditure of labor and other expense which is apparently within reason, and both the New Jersey and New York Commissions are endeavoring to develop methods for keeping inventories up to date in which it is hoped that the co-operation and approval of public utility companies in general may be secured.

DISCUSSION OF THE VALUE AND USE OF A CONTINUOUS INVENTORY

The desirability and the purposes for which an inventory and appraisal of a company's property is made have been generally

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discussed heretofore and the necessity of making such an inventory and appraisal under certain conditions is probably sufficiently apparent to eliminate the necessity of further discussion on this matter. Such inventory and appraisal of any large company is comparable to a general census which it has been customary to make at periodical intervals for centuries. If it were necessary or advisable to have the results of an up to date census available at frequent intervals the question would doubtless arise as to the desirability of keeping a complete census of all the people in the country up to date by other means than going out and counting them every five or ten years.

In the same way, if it is advisable or necessary to have available a total inventory and appraisal of a company's property at frequent intervals of time, it would seem advisable to consider the problems involved in maintaining such an inventory at all times.

If this kind of an inventory would serve no other purpose than in making data readily available for the compilation at any time of a total inventory and appraisal of the company's property, then the feasibility of doing so depends upon at least four factors.

1. The frequency with which it may be desirable.
2. The additional yearly expenditure required, multiplied by the number of years intervening compared with the cost of obtaining the results by a complete new inventory at a later period.
3. The comparative accuracy of an inventory by the two methods and the accuracy which is liable to be required in future appraisals.
4. The speed with which it may be desirable to compile the same.

A consideration of the frequency with which complete inventories are liable to be required leads to the conclusion that they are liable to occur much oftener in the future than in the past, as the custom of requiring yearly reports to various tax commissions and government regulating commissions appears to be becoming much more general and required in more detail than heretofore.

A consideration of the other factors involved in keeping a continuous inventory brings to light a number of other reasons and advantages to be obtained by carrying out such an undertaking. Besides the company itself, considered as a unit, there

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are at least three other classes of people who are interested in the operation of a public utility corporation.

1. The patrons or customers of the company.
2. The investors in the company's securities.
3. The general public, including the various governmental agencies representing this public.

A perpetual inventory of a company's property would be useful to any company in the following ways:

1. Data are made available for answering any complaints as to discrimination or overcharges in existing rates and the company should be able to present promptly a full statement of facts on the basis of which a satisfactory determination can be made.

2. The increased cost of labor and material renders it probable that many rate cases in the future will involve increases, rather than decreases in rates for services rendered and the company will need to be fortified with all necessary facts as to the cost of service rendered, among which are included as two of the principle items, a fair return on the investment and a yearly allowance toward a reserve fund for replacing the property involved, at the time that such replacement is needed.

3. In many rate cases and cases pertaining to security issues, inventories and appraisals have been made and depreciation and present value estimated. Various methods have been used for making these determinations and estimates of future depreciation have been made. There the matter, in most cases, has been dropped and the future depreciation has been left to take care of itself.

The cut and dried formulas for determining depreciation used in many cases have often been challenged and criticized. The criticism has been so severe that it is not at all unlikely that new methods will be adopted in the future which will depend upon changes which actually take place as time goes on and that will have to be checked up from time to time. Probably the surest check upon accruing depreciation or an accruing renewal fund is a comparison of the fund with the total cost of the property, subject to depreciation, which, of course, can only be made by having at hand an up to date inventory. It is quite probable that, in the future, one of the most urgent reasons for making an inventory and keeping it up to date will be the necessity of having some means for judging whether or not a company is making reasonable preparation for renewing and perpetuating its property.

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4. For most public utility companies, the approval of a State Commission is necessary for the issue of new securities. The labor and time involved in securing the approval of the same, both on the part of the company and of the Commission, would be materially reduced. There would be less interruption of the work performed by the operating force of the company from governmental inspectors, either in checking up construction expenditures for new securities or in making a complete appraisal of a company's property for this or other purposes.

5. The market for a company's securities would, doubtless, be increased by a general knowledge that a running inventory of all the company's property was maintained and consequently that some check was available upon the total property represented by securities issued and on the accounting methods followed by the company.

6. It would probably make available data for securing franchise extensions from various municipalities under more equitable terms than appears to be possible at present.

7. Data would be available for making investigations to satisfy the demands of labor employed in the company's operations as to whether they were, or were not, receiving a fair proportion of the company's revenue. One of the reasons privately advanced by labor union men for demanding an increased share in a company's revenue is that the books of many companies are kept in such a manner that the revenues are covered up in some way and their total income is not shown in the reports made to the stockholders or public bodies. Without commenting on the merits of this contention, it is probable that the means of proving or refuting it would be much more readily available than at the present time.

8. It is the general experience in checking up the books of various companies in New Jersey for approval of construction expenditures that comparatively little question can be raised as to the total amounts claimed, but that the distribution to the various items or accounts by which the expenditures are classified, are very frequently incorrect, which fact is generally brought out by making an inventory of the property acquired and checking up the unit prices. Hence there seems little doubt that a continuous inventory maintained by a company would be conducive to much more accurate accounting and distribution of charges between fixed capital and operating expenses as well as a more accurate distribution of general overhead charges than is possible at present.

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9. Insurance adjustment for fire and other losses could be more readily and equitably obtaind.

10. Tax Commission reports and yearly reports to regulating bodies could be more readily compiled.

11. At the present time a few large companies are keeping a more or less detailed record as to the location of their various items of property, especially of underground conduits, etc. Many companies, however, have very incomplete records as to just what they own or where it is located and information is not readily available as to what service they are able to render at a given location, either permanently or temporarily. As an illustration of this point, the case may be cited of a gas company which was recently called upon for service by a prospective customer in an outlying district. An employee of the company, to whom the request was made, replied that the company would be unable to make the connection to the customer's premises, as the company's mains were too far away. Later investigation proved that the company had a service connection to the house next door and that the main in the street extended to within about fifty feet of the prospective customer's lot. A continuous inventory would necessitate the keeping of records which would prevent these or similar occurrences.

12. In addition to requiring records which would give the location of property owned, the adoption of such a system in connection with a continuous inventory and appraisal would be of great value in promoting more efficient construction and operation, as detailed costs would readily be available from which the costs of rendering any particular service or of making any particular extension or betterment could be accurately determined.

Some of the advantages cited above would apply equally well to the company's customers, investors, and the public, but the above seem to be sufficient.

Preparation of the Inventory

This subject apparently implies first a complete inventory and appraisal of the property as of a given date but this is not a necessary prelude to the above, and, as most companies have not a complete inventory and appraisal of their property, it seems advisable to state that a company can readily start an inventory of all new property acquired from the present time forward and all old property withdrawn from service and either replaced

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or abandoned, without detailing a special force of engineers to make a complete inventory of all property. The record of the company's property in existence at the time the inventory is started can be obtained at such times as the company's engineers and accountants may be available for this work, and, in the course of a few years it might be possible in this manner to obtain a complete inventory.

The actual problem of maintaining a continuous inventory resolves itself into the question as to how small the units may be into which a property may be divided and records kept without an unreasonable expense, and how large the units of property may be taken without making indentification of any item or part of the property so uncertain as to destroy the accuracy of the inventory and subsequent changes in the capital account.

To illustrate, suppose a company builds today a large power station and ten years from now it builds an addition, removing one wall and making use of some of the material for the new work. Or, a company builds an overhead distribution system; five years later it becomes necessary to replace some of the existing wires on a certain street with a larger size; ten years later it is necessary to move a part of this same line to the other side of the street and install joint poles with another company, and fifteen years later it becomes necessary to replace all this construction with an underground system.

Is it possible to keep an accurate record of these transactions so that the capital account shall record the cost of the additions and the proper withdrawals in going through these various changes without relying on estimates of both quantities and costs to such an extent as to render the records questionable as to their accuracy? Heretofore it has been necessary to rely largely on estimates of the original cost of both labor and material in recording such transactions; but, with proper co-ordination and co-operation of the various departments concerned, we believe that the necessity of making estimates can largely be obviated, and the total cost installed in place at any particular period of time obtained without any great expense.

The fundamental requirement for accomplishing the above is an efficient "work order" system, also quite generally known under the head of "Authorizations for Expenditure" or some similar name. A work order system is in force in practically every company of appreciable size today, and with more or less modification can be adapted to give the records required.

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In order to obtain the necessary records for writing off the original cost of the property when it is retired, it is absolutely necessary that one additional step be added to this system as it is generally in force in most companies; viz, *an allocation of the cost of each piece of construction or property acquired must be made in detail when the work is completed, and preferably just before the work order is finally closed*, as such an analysis will frequently disclose inaccuracies in either debits or credits. This practise is followed by many companies to a certain extent at the present time, but must be applied to all work orders, and the final cost must be reduced to the same units that are liable to be needed in making estimates for withdrawals or additions. Unless the property acquired is going to last forever or be withdrawn from capital account as a unit, such an estimate must be made sometime, and there would seem to be no time when a more accurate analysis could be made than at the time the work is done or property acquired.

An analysis of costs made at this time would aid in checking up inaccurate distribution of labor and material, and it is very important to do this, as the fact must be recognized that all of these records are going to depend primarily for their accuracy on the proper distribution of labor and material by the construction foreman, and especial emphasis must be laid on this point.

Many companies are keeping at the present time an additional set of records which can be made to fit in nicely with a continuous or perpetual inventory. These records consist mostly of cards showing the location, type, size, and dates of installation, change in location, etc., of meters, transformers, poles and attachments, and possibly, in some cases, street lamps, services and similar items. As stated in the first section of this paper, such records are valuable for other than strictly inventory purposes but they are also essential for this purpose in connection with the forms suggested below.

The items of property for the purposes of inventory may be divided into four general groups as follows:

A. Those items which are large enough to be recorded individually or in small groups with one entry, but which are liable to be altered or changed in part; *e.g.*, buildings.

B. Items which may be recorded individually and which are withdrawn from service as a unit; *e.g.*, meters.

C. Items which must be recorded in units of length, pounds,

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or some similar units and miscellaneous items; *e.g.*, wires and cables, insulators, arresters, etc.

D. Those items of property which are usually carried in inventories at the present time and which are usually checked up by field inventory at regular intervals; *e.g.*, materials and supplies portable tools, office furniture, etc.

There may be considerable difference of opinion as to just what method should be followed in collecting the data required, but a general scheme could be followed for either a gas, electric railway or railroad, telephone or telegraph, water or sewer utility or a private industrial plant by classifying the property in the general groups indicated above about as follows:

A. 1. Land and right of way.
2. Building and structures.
3. Equipment of stations, buildings, etc.

B. Poles, transformers, meters and services for an electric company; meters, services, fire hydrants, lamps, etc. for a water or gas company and similar items for these or other companies.

C. Wires, cables, conduits, crossarms, insulators, for an electric company; feeder cable, trolley wire, straight track, etc., for railways; transmission and distribution mains for water, gas and sewer companies.

D. Office equipment, shop equipment, stable equipment, etc.

Forms for Group A

The general form of recording data for items in group A in detail is given on form 1.

These data should be obtained from the completion report of the work order, an extra copy of which it might be advisable to file with other inventory data.

The basis for estimating the unit prices for the cost of brick wall removed (mentioned on form 1) should be found in this completion report. A list of the quantities involved should be available from the information and plans in the hands of the engineer responsible for the new addition. With this information there should be need for very little estimating which is not based on actual facts.

The summary of all such property classified under any particular account for any particular division or subdivision could be recorded on form 2 and the totals for that account or division readily obtained by summing up the items, on such occasions as a total is desired, probably no oftener than once each year.

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Form 1

AMERICAN ELECTRIC CO.—*Subsidiary Co*.....
DIVISION—Northern LOCATION—14th St. Belleville File No. 5
Computer.....*Checker*.....*App'd by*....*Date* ..*Acct. No.* 118
SUBJECT Substation Buildings.....*Reference*.....*Sheet No.* 1
(*or other similar items in Group A*)

Auth. No. and page	Date acquired	Description—As originally acquired or of addition or withdrawal	Area—Size or No. of units	Original cost		Total cost corrected to date for additions, etc.	Est. remaining life
				Per unit	Total		
543-10	1911	1-Substation Building Brick on concrete fndn. Slate Roof, etc. 40′ × 30′ One Story & Basement.	1200 sq. ft. 20000 cu. ft.	$2.00 .12	$2400	$2400	50
1585-4	1916	Brick wall removed 30′x18′ High			200	2200	45
1586-4	1916	Addition 10′x40′	400 sq. ft. 6667 cu. ft.	2.50 .15	1000	3200	46.6

EXPLANATORY NOTES ON USE OF FORM NO. 1

Note 1—If any item of property subject to depreciation is acquired subsequent to date of first use, this fact should be indicated together with other information available as to original construction, date, cost, etc.

Note 2—Remaining life of 45 years is obtained by subtracting 5 years elapsed between 1911 and 1916 from 50 year life first estimated.

Remaining life of 46.6 years is obtained by computing a weighted average of $2200 at 45 years and $1000 at 50 years.

Note 3—Present value on a basis of straight line depreciation may be readily obtained by multiplying $3200 by ratio of 46.6 years to 50 years, giving 93.2% and $2982.

Form 2

AMERICAN ELECTRIC CO—*Subsidiary Co*.....
DIVISION Northern LOCATION All File No. 5
Computer.....*Checker*.....*App'd by*.....*Date*.....*Acct. No.* 118
SUBJECT Summary of Substation Buildings, 1916 *Sheet No.* 101
(*or similar item in Group A*)

Ref. Sheet	Item	Location	Date originally acquired	Cost to Jan. 1	Added	Withdrawn	Cost to Dec. 31	Present value Dec. 31	
								%	Amt.
1	SS Building	14th St. Belleville	1911	$2400.	$1000	$200	$3200	93.2	$2982.
2	ditto	First St. Nutley	1906	etc.					
					Transferred to sheet No. 1-10				

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Form 3

AMERICAN ELECTRIC CO.—*Subsidiary Co*.....

DIVISION Northern *LOCATION All* *File No.* 5

Computer....*Checker*....*App'd by*....*Date*.....*Acc. No.* 124

SUBJECT 5 *kw. Transformers Type X* *Reference*.....*Sheet No.* 1

(*or similar items in Groups B or C*)

Date	Ref. sheet	Number of units: Added	Withdrawn: No.	Withdrawn: Date orig. installed	Net total to date	Cost per unit	Total cost	Corrected total cost to date	Years: Av. Life units withdrawn	Years: Av. age units installed
Brought Fwd.		Inventory Jan.1,1916			250	$62	$15,500	$15,500		5.1
1916		40			290	61*	2,400	17,940		
1916			2	1900	288	65†	130†	17,810	16	
1916			3	1901	285	64†	192	17,618	15	
1916		Inventory Dec. 31,			285	61.82		17,618		5.08
1917										

* Average costs for all units of this size for any given period—say one year.

† Prices might be averaged and one figure shown or, if not much variation in price, they might be withdrawn at the average cost of the 250 shown at the beginning of the year

Form 4

AMERICAN ELECTRIC CO.—*Subsidiary Co*.....

DIVISION Northern *LOCATION All* *File No.* 5

Computer....*Checker*....*App'd by*....*Date*.....*Acct. No.* 124

SUBJECT Summary of Transformers—1916 *Sheet No.* 101

(*or similar item in Group B or C*)

Ref. sheet	Size	Type	Number of units: Jan. 1st.	Added	With-drawn	Dec 31	Cost of units: Jan. 1st	Added	With-drawn	Dec. 31	Av. cost per unit Dec. 31	Present value Dec. 31: %	Amt.
1	5 kw.	X	250	40	5	285	$15,500	$2,440	$322	$17,618	$61.82	74.6	$13.143
5	10 kw	X	100	20	2	118etc							

Transferred to sheet No. 1–10

Note:—"%" under "Present Value" for straight line depreciation would usually be obtained by comparing average age of units installed with average life of units withdrawn. In this case it is estimated that a 15 or 16 year life is not long enough and life base is arbitrarily taken as 20 years. In some cases it might be desirable to consider salvage in arriving at present value but it is disregarded above for sake of brevity.

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Forms for Groups B and C

The same forms are recommended for both groups B and C, but the method of collecting the data required is different.

For both groups it is thought best to use unit costs averaged for the district into which the company chooses to subdivide its territory, say a tax district, and for a certain period of time, monthly, quarterly, or yearly. The average for labor, storeroom charges, miscellaneous material items, overhead charges, etc., would necessarily need to be computed after the close of the current period or the average taken from the preceding period and final adjustments made for variation.

The total quantities for all items in group B, for which a card record is assumed to be made, can be computed either from the cards or from the completion reports of the work orders. Probably the total could be obtained more readily from the card records, whether tabulated by hand or sorted and tabulated mechanically by means of the Hollerith system of card records.

For all items in group C, the totals of both quantities and prices would probably best be obtained and reconciled with the amounts given in the completion reports of all work orders involved, although they might be obtained from field books or street maps showing construction changes for the required period, or from pole record and manhole record cards which usually indicate the wires, cables, conduit, etc., extending to the adjacent units.

Form 3 shows method of recording a group of similar units, viz., 5 kw. transformers and Form 4 shows method of summarizing units of various sizes.

Forms for Group D

Form 5 is recommended for summarizing items in this group as it is contemplated to include only such items as a company carries or could reasonably carry on an inventory which is usually made at the present time by actual count. This inventory as applied to office furniture, large portable tools, etc., usually gives the estimated present value of these items and they are carried into the property account each year at this depreciated value.

The first entry for each of these items is naturally the cost new and it is recommended that this cost new be carried in the inventory in a parallel column with the depreciated value until such time as the item is retired. Also, that the total cost new of

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Form 5

AMERICAN ELECTRIC CO.—*Subsidiary Co*.....

DIVISION Northern *LOCATION* Belleville Office *File No.* 5

Computer....*Checker*....*App'd by*....*Date*.....*Acct. No.* 107

SUBJECT General Equipment, Dec. 31, 1916 *Ref*.....*Sheet No.* 101

(*or similar items in Group D*)

Quantity	Unit	Item	Year acquired	Original cost			Present value	
				Ref.	Unit	Amt.	%	Amt.
2		Typewriters.....	1914	52	$79	$158	75	$118
2		Typewriter desks.....	1912	35	20	40	80	32
6		Bent wood chairs.....	1916	Bill	3	18	100	18
		Totals, Dec. 31.....				$216	77.7	168
		Additions 1916.....				18		
		Total of items Jan. 1.....				$198		
		Totals per inventory 12-31-15		61		210		
		Withdrawals 1916.....				$12		

Transferred to sheet No. 1–10.

Form 6

AMERICAN ELECTRIC CO.—*Subsidiary Co*.....

DIVISION Northern *LOCATION*.....*File No.* 5

Computer....*Checker*....*App'd by*....*Date*.....*Acct. No.* 1

SUBJECT Grand Summary, 1916 *Sheet No.* 10

Acct. No.	Ref. Sheet	Item	Total cost				Present value	
			Jan. 1	Added	Withdrawn	Dec. 31	%	Amt.
101	5	Land, etc.....						
107	101	General Equipment.....	$210	$18	$12	$216	77.7	$168
118	101	Substation Bldgs.....	2400	1,000	200	3,200	93.2	2,982
124	101	Transformers.....	15,000	2,440	322	17,618	74.6	13,143
		Totals Northern Div. 1916	18,110	$3,458	$534	21,034	77.5	16,293

EXPLANATORY NOTES IN REFERENCE TO USE OF ABOVE FORMS.

Note 1. Loose leaf sheet 8½"x11" is recommended for all forms.

Note 2. For all withdrawals use red ink.

Note 3. Forms 1 and 3 constitute the continuous record. All other forms are made up when it is desired to arrive at totals and are correct for one date only. If periods used are different than calendar year, forms would be slightly modified.

Note 4. Provision for identifying computers, etc. on forms 1 and 3 after first entries could be made by having initials inserted in date column or by providing separate column.

Note 5. Figures carried to grand summary, form 6, are merely illustrative and not the totals which would be obtained if more entries were made on forms 2, 4, and 5.

Note 6. From totals on form 6, the amount of additions for which new securities may be issued may be readily determined.

Note 7. By comparing form 6 as filled out for 1915 with year 1916, the credit which must be made to reserve account from earnings to provide for the year's depreciation may be determined.

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all items be carried in the property account; and that the estimated accrued depreciation of all such items should be carried in the depreciation reserve account instead of being charged directly to operation each year and lost sight of thereafter as is the practise with many companies today.

A comparison of such an inventory at the end of any year with the preceding will indicate the total value of all withdrawals and additions and a proper adjustment can then be made in one lump sum between the capital account and the depreciation reserve.

Form 6 is to be used as a summary of all property and probably needs no explanation in addition to notes given.

To carry out the above, it would seem advisable to create a separate department under the joint supervision of the chief engineer, general auditor or controller, and the official in charge of the Public Relations Committee of a utility if such a committee exists. The man in charge of this department should understand both engineering, accounting and statistical work, and be capable of co-operating with all other departments of the company to secure the full benefits possible to be derived as outlined in the first section of this paper.

The methods indicated above would necessarily need to be modified to suit the needs of any individual company, and in actually working out the same, it is probable that some modifications of the present system of records and accounting could be adopted which would materially lessen the amount of additional work which might appear to be necessary at first glance in inaugurating such a system of continuous inventory and appraisal.

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To be presented at the 326th meeting of the American Institute of Electrical Engineers, New York, November 10, 1916.

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GROWTH AND DEPRECIATION

BY JULIAN LOEBENSTEIN

ABSTRACT OF PAPER

It is generally assumed that a complex utility property will depreciate to an approximately fixed per cent condition. This is shown by theoretical and actual curves to be incorrect. It is shown that the manner of the company's growth affects its per cent condition.

The necessity for reserves, the manner in which they may be kept and the return which should be allowed on them, whether reinvested or not, is discussed. Several Commission and Court decisions are quoted to show the tendency to disallow a return on a reserve and arguments are presented in refutation of the decisions.

The principal points are as follows:

1. The condition of a property is dependent not only on maintenance but also on its growth.
2. Property does not settle down to a fixed per cent condition.
3. Capital is kept intact by reinvesting reserve in extensions. Under this condition, depreciated value of the entire property is the fair one for rate making purposes.
4. For a company unable to use reserve in extensions a liquid depreciation fund will be necessary.
5. The same return, available for dividends, should be allowed on a reserve as on the remainder of the property.

IN THIS article the writer tries to bring out the following points:

First, to show that the per cent condition of any property is dependent not only upon the maintenance but upon the past and present growth.

Second, to show that under practically no condition will it be necessary to bring a property back to one hundred per cent condition, but that it does not settle down to some fixed per cent condition less than one hundred per cent. It does, however, go through a repeating cycle of conditions, one point in the cycle being a maximum above which it will never rise. This maximum point will depend entirely upon the growth of the property and should be studied separately for each property under consideration.

Third, to show that under certain conditions of growth, a

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growing company need keep no liquid depreciation reserve fund; that it may reinvest the reserve in extensions, making renewals as they come due in any given year, from the amount set aside for depreciation reserve in that year, and that by so doing the stockholders' capital is kept intact, yet the depreciated value of the whole property is the fair one, both for consumer and stockholder, for rate-making purposes.

Fourth, to show that for a company which has stopped growing or for one which is growing at a rate not large enough to use all of the depreciation reserve for reinvestment in extensions, it will be necessary to have a continually varying amount in a liquid depreciation reserve fund, and that this amount will fluctuate in a manner depending upon the company's growth.

Fifth, to show that since such a liquid reserve may be necessary for a growing company and will be necessary for a company which has ceased to grow, that the same return should be allowed on such a reserve as on any other capital invested in the property, and that such return should be available for dividends, provided that the cost new, less depreciation, is to be used as a basis for making the rates.

The following definitions and assumptions are made in the discussion. By liquid depreciation reserve fund is meant a reserve either as cash in a bank, invested in bonds or employed in any other way so as to be readily convertible into cash for immediate use. This is to distinguish it from depreciation reserve, which is invested in extensions and betterments and which cannot be readily turned into available cash. No consideration is taken of scrap value nor of a reserve for emergencies or catastrophies as the calculations are not in any way affected by such a fund, the effect being simply to refer them to a different ordinate. All calculations are on the straight line basis and all properties considered are assumed to be kept in the best state of repair. It is assumed that the depreciated value of the property will be used as a basis for making the rates.

Before attempting to draw any conclusions from the tables, it is advisable to show how they were constructed and calculated. Table I is the calculation for a property in which a uniform capital investment of $1000 a year is made for ten years and the property then stops growing. All the elements of the property are assumed to have a ten year life. Table II shows a property similar in all respects but one, to that shown in Table I. In Table II the uniform investment is made for only five years of

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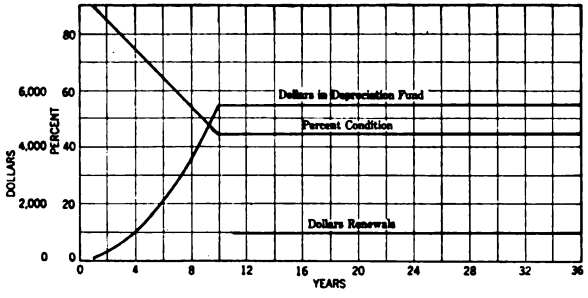
the ten. Table III is for a property the elements of which have a ten year life. In the first year the capital investment is $1000. In the second year the depreciation fund is used for

TABLE I.

UNIFORM YEARLY INVESTMENT FOR TEN YEARS

End of Growth—Tenth Year
Life—Ten Years
Depreciation reserve not invested in extensions

End of year	Capital invest. for the year	Total capital expenditures	Increment to Depr. fund	Deduction from depr. fund	Total in depr. fund	Percent condition
1	1000	1,000	100	0	100	90
2	1000	2,000	200	0	300	85
3	1000	3,000	300	0	600	80
4	1000	4,000	400	0	1000	75
5	1000	5,000	500	0	1500	70
6	1000	6,000	600	0	2100	65
7	1000	7,000	700	0	2800	60
8	1000	8,000	800	0	3600	55
9	1000	9,000	900	0	4500	50
10	1000	10,000	1000	0	5500	45
11	—	10,000	1000	1000	5500	45
12	—	10,000	1000	1000	5500	45
13	—	10,000	1000	1000	5500	45
14	—	10,000	1000	1000	5500	45
15	—	10,000	1000	1000	5500	45
16	—	10,000	1000	1000	5500	45
17	—	10,000	1000	1000	5500	45
18	—	10,000	1000	1000	5500	45
19	—	10,000	1000	1000	5500	45
20	—	10,000	1000	1000	5500	45



CURVE I—UNIFORM INVESTMENT FOR TEN YEARS

End of growth, tenth year—life, ten years—depreciation reserve not invested in extensions.

investment in extensions and enough additional capital is invested to bring the investment of both capital and reserve for the year, up to $1000. The same procedure is followed each

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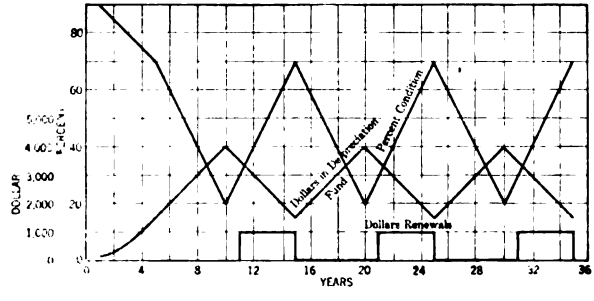
year until at the end of the tenth year the property ceases to have any further additions. Table IV is for a property the elements of which have a ten year life. Starting with an invest-

TABLE II.

Uniform yearly investment for five years
End of growth—fifth year
Life—ten years
Depreciation reserve not invested in extensions

End of year	Capital invest. for the year	Total capital expenditures	Increment to depr. fund	Deduction from depr. fund	Total in in depr. fund	Percent condition
1	1000	1000	100	0	100	90
2	1000	2000	200	0	300	85
3	1000	3000	300	0	600	80
4	1000	4000	400	0	1000	75
5	1000	5000	500	0	1500	70
6	—	5000	500	0	2000	60
7	—	5000	500	0	2500	50
8	—	5000	500	0	3000	40
9	—	5000	500	0	3500	30
10	—	5000	500	0	4000	20
11	—	5000	500	1000	3500	30
12	—	5000	500	1000	3000	40
13	—	5000	500	1000	2500	50
14	—	5000	500	1000	2000	60
15	—	5000	500	1000	1500	70
16	—	5000	500	0	2000	60
17	—	5000	500	0	2500	50
18	—	5000	500	0	3000	40
19	—	5000	500	0	3500	30
20	—	5000	500	0	4000	20



CURVE II—UNIFORM YEARLY INVESTMENT FOR FIVE YEARS

End of growth, fifth year—life, ten years—depreciation reserve not invested in extensions.

ment of $1000 the first year, the investment decreases one hundred dollars per year until the tenth year, at which time the property stops growing. The depreciation reserve is not re-

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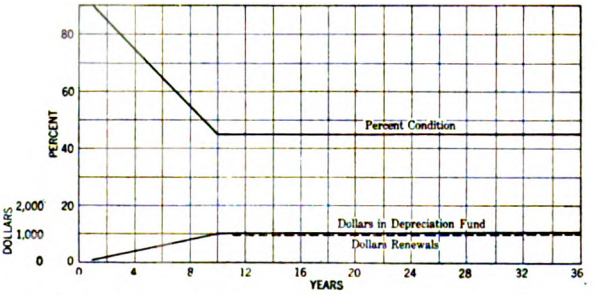
TABLE III.

Uniform yearly investment for ten years
End of growth—tenth year
Life—ten years
Depreciation reserve invested in extensions

End of year	Capital Invest. for the year	Total capital expenditure	Investment for the year from depr. reserve	Total investment capital plus reserve	Increment to depr. fund	Deduction from depr. fund	Total in depr. fund	Percent condition
1	1000	1000	—	1,000	100	—	100	90
2	900	1900	100	2,000	200	100	200	85
3	800	2700	200	3,000	300	200	300	80
4	700	3400	300	4,000	400	300	400	75
5	600	4000	400	5,000	500	400	500	70
6	500	4500	500	6,000	600	500	600	65
7	400	4900	600	7,000	700	600	700	60
8	300	5200	700	8,000	800	700	800	55
9	200	5400	800	9,000	900	800	900	50
10	100	5500	900	10,000	1000	900	1000	45
11	—	5500	—	10,000	1000	1000	1000	45
12	—	5500	—	10,000	1000	1000	1000	45
13	—	5500	—	10,000	1000	1000	1000	45
14	—	5500	—	10,000	1000	1000	1000	45
15	—	5500	—	10,000	1000	1000	1000	45
16	—	5500	—	10,000	1000	1000	1000	45
17	—	5500	—	10,000	1000	1000	1000	45
18	—	5500	—	10,000	1000	1000	1000	45
19	—	5500	—	10,000	1000	1000	1000	45
20	—	5500	—	10,000	1000	1000	1000	45



CURVE III—UNIFORM YEARLY INVESTMENT FOR TEN YEARS
End of growth, tenth year—life, ten years—depreciation reserve invested in extensions.

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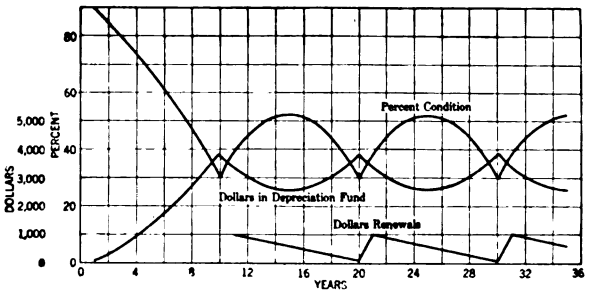
invested. Table V shows a property consisting of two life groups having lives of ten and twenty years respectively. Starting with a capital investment of five hundred dollars for each of

TABLE IV.

Decreasing yearly investment for ten years
End of growth—tenth year
Life—ten years
Depreciation reserve not invested in extensions

End of year	Capital invest for for the year	Total capital expenditure	Increment to depr. fund	Deduction from depr. fund	Total in depr. fund	Depreciated value of property	Percent condition
1	1000	1000	100	—	100	900	90.0
2	900	1900	190	—	290	1610	84.6
3	800	2700	270	—	560	2140	78.3
4	700	3400	340	—	900	2500	73.6
5	600	4000	400	—	1300	2700	67.5
6	500	4500	450	—	1750	2750	61.0
7	400	4900	490	—	2240	2660	54.3
8	300	5200	520	—	2760	2440	47.0
9	200	5400	540	—	3300	2100	38.9
10	100	5500	550	—	3850	1650	30.0
11	—	5500	550	1000	3400	2100	38.2
12	—	5500	550	900	3050	2450	44.5
13	—	5500	550	800	2800	2700	49.1
14	—	5500	550	700	2650	2850	51.7
15	—	5500	550	600	2600	2900	52.8
16	—	5500	550	500	2650	2850	51.7
17	—	5500	550	400	2800	2700	49.1
18	—	5500	550	300	3050	2450	44.5
19	—	5500	550	200	3400	2100	38.2
20	—	5500	550	100	3850	1650	30.0



CURVE IV— DECREASING YEARLY INVESTMENT FOR TEN YEARS

End of growth, tenth year—life, ten years—depreciation reserve not invested in extensions.

the groups, the capital investment is incrased one hundered dollars a year for each group for the ten years. In each year an equal amount has been reinvested in each life group, so that the

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total of such investments for any given year is nearly equal to the amount set aside in the depreciation reserve the year before. This continues up to and including the tenth year after which time further investments are discontinued, but renewals are made as each portion of the original investment reaches the end of its life.

It may be well here to point out something worthy of note which developed in the course of the calculation. It will be seen, by reference to Table V, that in every case, the sum of the dollars remaining in the fund (column 15) and the depreciated value of the property (column 17) giving (column 18) the total value of the property, is the same as the total capital expenditure (column 6). This furnishes a short method of calculating the depreciated value of the property *i.e.* by subtraction instead of by the depreciation of each year group. Take for example the tenth year: the long method is:—

Dollars	Per cent remaining value	Dollars remaining value
500	0	0.00
500	50	250.00
630	10	63.00
630	55	346.50
790	20	158.00
790	60	474.00
940	30	282.00
940	65	611.00
1100	40	440.00
1100	70	770.00
1300	50	650.00
1300	75	975.00
1500	60	900.00
1500	80	1200.00
1700	70	1190.00
1700	85	1445.00
1950	80	1560.00
1950	90	1755.00
2150	90	1935.00
2150	95	2042.50
		$17,047.00

This $17,047, the depreciated value of the property, as obtained above, plus $1953, the dollars in the depreciation fund, is equal to the total capital expenditure of $19,000. The short method is therefore, to subtract the dollars in the depreciation

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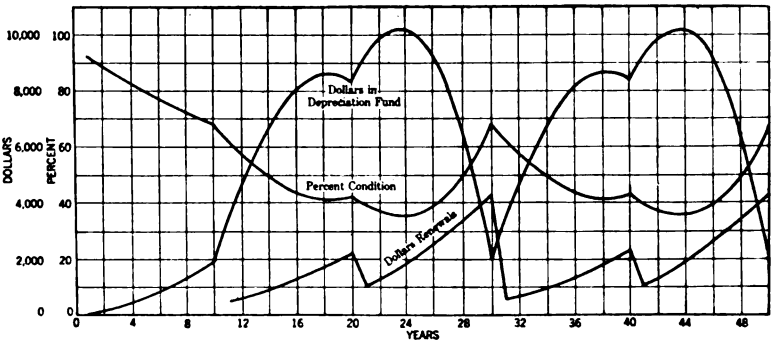
fund from the total capital expenditure to get the depreciated value of the property. This method was followed in the calculation of the table.

It is generally considered that a property maintained in good operating condition will be between 70 and 85 per cent new. In fact, Whitten, in his Valuation of Public Service Corporations, discussing depreciation says, (Vol. I, page 358, par. 421) "It has been stated that a street railway maintained in good operating condition will necessarily show cost less depreciation of from 70 to 85 per cent of the cost new". That this is an entirely fallacious assumption and that the percent condition of any property is not only a function of its maintenance, but also



CURVE V—INCREASING YEARLY INVESTMENT FOR TEN YEARS

Life { one group, ten years / one group, twenty years

End of growth, tenth year—depreciation reserve invested in extensions.

most decidedly of the manner of its growth, is shown by the accompanying tables and curves.

It is now an easy matter to prove that Mr. Whitten's assumption is wrong, and also to prove the first point, which is that the per cent condition of any property is dependent not only on the maintenance, but upon the past and present growth. Referring to the tables, we see that in Table I and Curve I, where there has been a uniform investment over a term of years corresponding to the life of the property, the per cent condition varies from 90 to 45 during that term, and then stays at 45 when the property stops growing. The per cent condition appears as 45 instead of the proverbial 50 because, in the calculations, the end, instead of the beginning of the tenth year is considered. In Table II and Curve II, where there is a uniform investment

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page 358, par. 421) "It
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That this is an entirely
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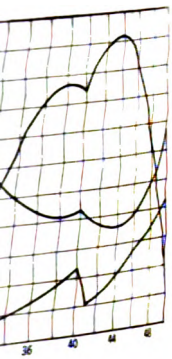

FOR TEN YEARS

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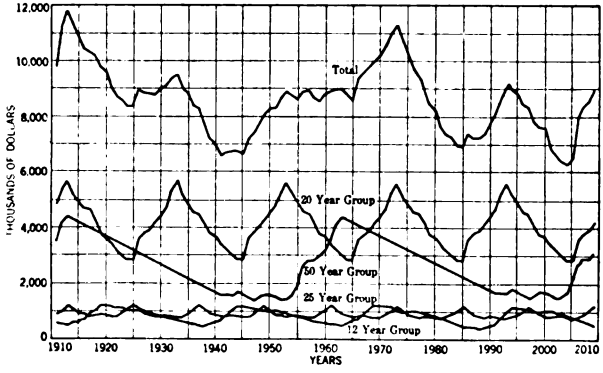
over a term of years not corresponding to the life of the property, the per cent condition varies from 90 to 70, while the property is growing. After that it varies in repeating cycles from 70 to 20 and back to 70 again. This, of course, is an extreme case, but it shows the possibilities of variation. Table III and Curve III show the same characteristics as Table I, although in Table I there is no reinvestment of reserve, while in Table III there is. Table IV and Curve IV show a more complicated property than the others. Here the variation during the ten years the property is expanding, is from about 92 to about 67. It then goes through a repeating cycle whose period is twenty years, varying from 67 to 35 per cent and back again.

Thus it may readily be seen that a company which grows at an



CURVE VI—DEPRECIATED SERVICE VALUES OF AN ACTUAL PROPERTY
End of growth assumed Dec. 31, 1913—original service value $16,500,000—maximum per cent condition 69.0 per cent—minimum per cent condition 37.5 per cent.

increasing rate will have a lower per cent depreciation in any given year, than a company which grows at a uniform rate, all other conditions being assumed the same. Furthermore, if both companies reach their maximum growth at the same time thereafter their per cent condition will vary one from the other; first, because of the discrepancies between the terms over which the investments have been made and the life terms of the groups (compare Tables and Curves I and III) and second, because of the dissimilar manner in which the investments have been made (compare Tables and Curves IV and V).

Moreover this is borne out not only by the theoretical calculation, but Curve VI shows this condition for an actual electric property. The company was assumed to have reached its final

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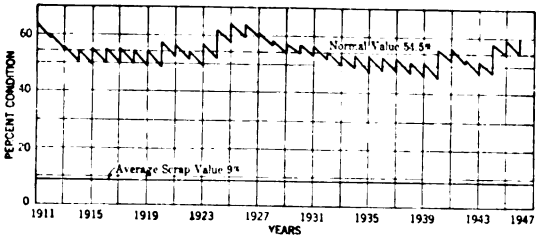
growth on December 31st, 1913 after which date only renewals were made. The total service value of all the property was approximately $16,500,000 yet it may be seen from the curve that the actual service value varies from $6,200,000 to $11,000,000 or from 37.5 per cent to 69 per cent. Now, even supposing that some of the assumptions as to probable life are incorrect, the property will still vary over a wide range and not be in any popularly supposed fixed condition somewhere between 70 and 85 per cent. Curve VIII is for another actual property but a much smaller one than that considered in Curve VI. The property is assumed to reach its full growth in 1912, and the remaining service value is shown for the next 53 years. The service value varies from $810,000 to $370,000 or a corresponding per cent variation from 77 to 35.



CURVE VII—TOTAL COMPOSITE THEORETICAL VALUE CURVE OF THE DEPRECIABLE PROPERTY OF THE UNITED RAILWAYS CO. OF ST. LOUIS AS GIVEN IN THE REPORT ON THAT PROPERTY BY THE ST. LOUIS PUBLIC SERVICE COMMISSION—1912

Before passing to point two, it is pertinent to quote again from Whitten, who says, (Vol. 2, page 1127, par. 1285). "We know, however, that there is a tendency for all utilities to settle down after a time to a more or less uniform condition as regards the percentage amount of accrued depreciation, and the annual requirements for renewals and replacements. After the various parts of a large public utility plant have gone through complete cycles of renewals, the plant settles down to a condition in which, saving extraordinary functional depreciation, expenditures for maintenance, repairs and renewals become practically constant. There is little fluctuation from year to year and the averages by five or ten year periods are practically identical. This settling down or equalizing process, is very greatly hastened by the fact that all large systems are constructed piecemeal."

The above theory, which the writer has tried to refute, is

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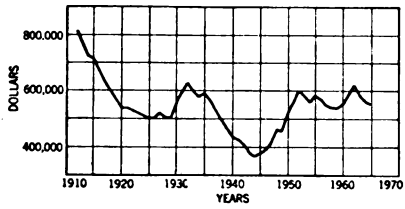
also supported by Mr. James E. Allison, Chief Engineer of the St. Louis Public Service Commission, who in the report on the United Railways Company of St. Louis, presents the curve which is here reproduced as Curve VII. He says, (Appendix A, page 89):

"It has been the purpose of the writer to show by diagrams that piecemeal built properties of any complexity, will eventually assume a theoretical value curve, closely conforming to the straight normal value line, halfway between 100 per cent and the composite scrap value of the property."

It cannot be denied that the curve which he gives most certainly is a uniform curve and tends to support his theory. It should be noted though, that even his curve varies over a range of 15 per cent during the comparatively short time of 13 years, and although 15 per cent is small, it takes a different aspect when considered as 15 per cent of $30,000,000, the approximate value of the property, or $4,500,000.



CURVE VIII—DEPRECIATED SERVICE VALUES OF AN ACTUAL PROPERTY

End of growth assumed Dec. 31, 1912—original service value $1,056,917—maximum per cent condition 77.0 per cent—minimum per cent condition 35.0 per cent.

As previously stated, the curve shown by Mr. Allison, is a remarkably smooth one, but when compared to Curves VI and VIII, it shows the danger of drawing a general conclusion from any one curve. Every complex property undoubtedly displays the tendency which Mr. Allison points out, but it would be decidedly unsafe to apply it indiscriminately to any property. The point is that each property should be investigated separately to determine its characteristics in this respect.

The second point, to show that under practically no condition will it be necessary to bring a property back to 100 per cent condition, has already been presented by many other writers, but it is given here again in conjunction with the conclusion from point number one. It is obvious that any property which has been built up gradually and not all at once, will have its various parts wear out in a similar sequence to that in which they were installed. Since different portions of the property will have to be replaced each year, it will never be necessary to replace all of them at once and so bring the property back to one hundred per cent condition.

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As far as the point just made goes, most writers are agreed, but having reached that conclusion they claim that the property remains at a certain fixed condition, the exact per cent depending on the maintenance.

It is perfectly true that the entire property will not have to be renewed at any one time but only in the condition where there has been a uniform growth over a term of years corresponding to the life of the property (see Table I and Curve I) will the property reach a fixed condition and remain there after the property has stopped growing. Also, as long as a property is growing whether uniformly or otherwise, there will be a variation in its per cent condition. In other words, there is an obligation to renew varying amounts of property in different years in the future, and any calculation of reserves based on an assumption that because of perpetual life the company will reach a stable condition either during or after its growth is entirely incorrect.

It will be noticed from an examination of the tables that while the property is growing, the per cent condition is decreasing, the rate of decrease varying inversely with the rate of growth. When the property stops growing it has reached a certain per cent condition and thereafter it varies between that condition and some other, dependent upon the manner of growth. When the growth stops the property may be at a minimum per cent condition, as in Table IV and Curve IV, where there has been a decreasing rate of growth; or at a maximum as in Table V and Curve V where there has been an increasing rate of growth. Table IV and Curve IV show that the property will vary between 30 and 53 per cent, while Table V and Curve V show, in that case, a variation of from 35 to 68 per cent.

From the above figures it is evident that each property, should it stop growing, will go through a cycle in which it reaches a certain maximum condition less than 100 per cent, this maximum condition being entirely dependent on the manner of the property's growth.

It may be argued that the writer has made arbitrary and special assumptions in taking cases where the period of growth corresponds to the life of the property, but both Tables II and V are based on other assumptions. Besides this, it is worth bearing in mind that any property may be divided into a series of groups in which the investment term corresponds to the life term, and that each of these groups will follow a condition curve of its own. For a complex property, therefor, there would be

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a series of such curves which would give a resultant one. This resultant curve, however, would also vary over a considerable range. This is borne out by Curves VI and VIII of actual properties.

Since it will never be necessary to renew the entire property, some of the reserve necessary to return it to the 100 per cent condition may be dispensed with. It is not correct, however, to say that since the reserve will never be needed it should not be obtained. The stockholder has a right to expect that his capital be kept intact at 100 per cent. How then is the reserve to be handled? This is taken up as the third point.

There are three conditions which may be used as divisions for the consideration of the laying aside and use of depreciation reserve. These are:

1. Company growing at the great enough rate to permit the investment of all the reserve in extensions.

2. A company not growing at a great enough rate to permit the investment of all the reserve in extensions.

3. A company which is not growing.

Take the first case, where a company is growing at a great enough rate to permit the investment of all the reserve in extensions. It is clear that the annual charge for depreciation will, in some years be less, and in some years more, than the cost of renewals. In those years that the cost of renewals is less than the charge for depreciation, the difference may be invested in extensions, and in those years in which the cost of renewals is greater than the depreciation charge, it will be necessary to issue securities with the extensions made from reserve as a basis, using the money from the securities for the renewals. The securities, however, should not be issued to an amount greater than the depreciated value of the extensions. Wherever the depreciation reserve is invested in extensions, it is necessary to keep a careful record of property of this class. It is essential that separate accounts be kept for capital investment and reserve investment. The trouble in the past was that no attempt was made to keep them separate.

In the second case, where the company is not growing at a great enough rate to permit the investment in extensions of the difference between depreciation charge for the year and renewals for the year, and in the third case where the company has stopped growing, it will be necessary to keep the surplus of annual allowance over cost of renewal for certain years, in a liquid

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reserve fund, so as to be able to make up the deficiencies in other years. That some money must be so kept is now clear, for point one shows the wide fluctuations in per cent condition and in yearly renewals. How much must be so kept will be discussed under point four.

At present it is interesting to consider in what years the peak demands, requiring a security issue for the first case and a withdrawal of money from the liquid reserve in the second and third cases, will fall. In any complex property there are groups of things having different costs and different lives installed in the same and different years. If the cost is considered as amplitude, the lives as frequency, and the years as phase displacement it may readily be seen that as different waves come into step and pass out again, peaks and valleys will occur. In order to determine the variation in renewal charges it will be necessary to make tables and plot curves of the future renewals in each group. These curves will take the same general form as those in Curve VI, but will be for total replacement costs, instead of remaining service value as shown there. If tables are once compiled it is a simple matter to change them yearly as further extensions are made in the various groups. By following such a plan it will be easy to see whether or not adequate provision is being made for the handling of future extensions and to predict in what years it will be necessary to issue securities.

As described in the introduction, the second portion of point three is to show that by reinvesting depreciation reserve in extensions, the stockholders' capital is kept intact, yet the depreciated value of the property is the fair one for rate making purposes both from the point of view of the consumer and the stockholder.

Table V is for a property in which the depreciation reserve is invested in extensions. Let us consider the tenth year. Here the total expenditure on the property both from capital and reserve is $25,120, which has depreciated to $17,047. This latter sum plus $1953, which has been accumulated in the depreciation reserve during the past year and which as yet could not be reinvested, gives $19,000 the capital expenditure. Therefor, with the exception of the amount ($1953) accumulated in the reserve fund during the current year and not yet invested, the depreciated value of the property is equal to the capital investment. Omitting for the time being the question of allowing a return on the $1953 not reinvested, it is seen that allowing a

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return on the depreciated value of the property is practically equivalent to allowing a return on the original investment. The question of allowing a return on the amount held as liquid depreciation fund ($1953) in the above case will be considered under point five. This procedure described above, is therefor fair to the consumer, for he is paying a return on the value of the property in use, and it is fair to the stockholder for he is earning a return on his original capital.

The fourth point is to show that for a company which has stopped growing or for one which is growing at a rate not large enough to use all of the depreciation reserve for reinvestment in extensions, it will be necessary to have a continually varying amount in a liquid depreciation reserve fund and that this amount will fluctuate in a manner depending upon the company's growth.

Table V shows the condition for a property which has ceased to grow after ten years. At the end of the tenth year there are $1953 in the reserve. The sum laid aside annually for depreciation after that is $1884, yet owing to the fact that the company has grown faster at one time than at another, in some years there will be less than $1884 used for renewals and in some years more. The effect of this is to accumulate a fund over a certain period of years which is used over another period of years. Thus, starting with $1953 in the tenth year, the fund reaches a maximum of $10,149 in the twenty-fourth year; after which it decreases to $1953 again in the thirtieth year. This is graphically shown in Curve V. It is evident that since the $1953 will never be used as far as renewal purposes go, it may as well be returned to the stockholders. Since it is assumed that the company has stopped growing, the hypothesis precludes the possibility of using it for extensions and it should therefor be returned to the stockholders in the form of cash. It should be clearly understood by the stockholders that this is a return of capital and not a dividend payment.

Curve V is for the conditions assumed for this particular case. Any other manner of growth would give a different curve. In order to tell for any other property just what accumulation would take place and to determine how much, if anything, may be returned to the stockholders because it will never be used, it would be necessary to make a study similar to the one shown.

It is not very difficult to see that for a company which is growing, but at a rate too small to use all the reserve, that portion of the reserve which is not invested in extensions and betterments

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will bear the same relation to the renewals as the entire fund does in the case where the company is not growing at all. That is, there will be an accumulation curve for the liquid reserve which will be similar to the curve for a non-growing property.

In either case there will be a necessity for a liquid depreciation reserve for renewals and this reserve will vary from year to year. This fluctuation may be likened to the storage of energy in a flywheel. Just as there is no way to remove the energy from the flywheel except by stopping it, so there is no way of avoiding the fund as long as it is desired to make the renewals as they fall due. While the energy is stored in the flywheel it is of no direct use; yet it would be impossible to run the engine without a flywheel. The energy must be so stored to make it instantly available. The depreciation fund must also be stored to make it instantly available.

The fifth point is to show, that since such a liquid depreciation reserve may be necessary for a growing company and will be necessary for a company which has ceased to grow, that the same return should be allowed on such a reserve as on any other capital invested in the property, and that such return should be available for dividends, provided that the cost new, less depreciation is to be used as a basis for rate making.

Before trying to prove this point, the following decisions are given to show the stand taken in some cases in regard to this matter. The Nebraska State Railway Commission says in Re Application of the Lincoln Telephone and Telegraph Company, for authority to increase rates (A. T. & T. Co., Com. L.134 June 26, 1913, Nebraska State Railway Commission) "It will also be the policy of the Commission to expect of the corporation that it shall, so far as possible, use the depreciation funds . . . . in making extensions and betterment of the plant. Such part of the plant as is represented by the investment from the depreciation reserve shall be permitted to earn the same ratio of return as the stockholders' investment, but neither such reserve fund nor the earnings therefrom shall be available as dividends to stockholders, or for any other purposes than those set out."

In this decision the commission allows a return but it seems to consider the reserve as a sinking fund, the returns on which must be put into the fund. Further, it differentiates between investment from reserve and stockholders' investment as though the depreciation reserve were not also stockholders' investment.

In the Louisville and Nashville R. R. Co. v. Railroad Commis-

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sion of Alabama the special master says (U. S. Circuit Co., Middle Dist. of Alabama. Report of Wm. A. Gunther, Special Master in Chancery, 1911) "The defendants further insist that interest should be allowed on the balance in the replacement account. It is a mistake to suppose that such a charge is proper."

Also in the case of the Louisiana R. R. Commission vs. Cumberland Telephone Co., (212 U. S. 425) the Court says: "That it was right to raise more money to pay for depreciation than was actually dispersed for the particular year there can be no doubt, for a reserve is necessary in any business of this kind, and so it might accumulate, but to raise more than money enough for the purpose and place a balance to the credit of capital upon which to pay dividends cannot be proper treatment."

There are two chief arguments against allowing a return on the depreciation fund. The first applies only to that portion which is not invested in extensions. It is to the effect that since the fund is lying idle, bringing no return, or is at best invested in bonds bringing a low return, that this is all the return to which it is entitled. The second argument applies either to the case where there is a liquid reserve or the reserve is invested in extensions. It is to the effect that since the money for the reserve is furnished by the consumer, he should not further be required to pay a return on it.

Taking the second argument first. The whole discussion hinges to a large extent on the question as to whether or not the stockholder may expect that his capital be kept intact at 100 per cent. How many men would go into a business of any kind if they could not make enough to replace their capital goods as they wore out and besides earn a return on their investment? That all businesses do not do this does not alter the fact that they expect to do so when they start. The recognition of depreciation and the allowance therefor is in itself an acknowledgment of the correctness of keeping the capital intact.

The capital which is wasting away is certainly the capital of the stockholder. He uses up his capital in the service of the consumer and the consumer replaces the capital so used. The consumer is making a just restitution. He is replacing something which originally belonged not to him but to some one else. Why then should the replaced capital have a different status from the original? It should not. The capital in a depreciation reserve fund should be treated the same as any other capital. It should be allowed the same return and for the same purposes.

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Some argue that since the depreciation fund is lying idle (*i.e.* that portion not invested in extensions) or at best is invested where it brings only a low return, it is not entitled to more than it can earn. But is it lying idle? It has been shown that for any other than a growing company which can invest the entire reserve in extensions, there will necessarily be a continually varying amount in the liquid reserve. Besides this, even a growing company will have to carry from year to year some of the fund which it cannot reinvest at once. Is the depreciation reserve not just as necessary a part of the business as the working capital, of which there must always be a more or less fluctuating excess earning a low return, but which no one denies is entitled to the same rate of return as the capital actually invested in useful physical property? Is the liquid reserve, which is the stockholders' capital, not a guarantee to the consumer that the property will be maintained in first class operating condition and so give him the best of service? It may be said that he has a right to expect good service, but most people when not considering a public utility are willing to pay extra for good service. Thus, under competitive conditions a company which kept no reserve could give service at a lower rate than one which did, but it would be neither as good nor as reliable as that furnished by a company which kept a reserve. Would the public not be willing to pay for the greater reliability and better service?

No one questions the fairness of the proposition that the company be made to pay interest on deposits of consumers, yet in viewing that question the only consideration is that the consumer is deprived of the use of his money and should receive a recompense for it. The corporation's use of his money is not thought of for a moment in deciding whether or not such a charge is fair. To be sure, the company may devote it to a profitable use, but assuming that the company was not on a paying basis would that in any way alter its obligation to pay interest on the deposit? The stockholder is in much the same position as the consumer described above. He is deprived of the use of some of the money; but why should there be any further consideration of the justness of allowing him a return, regardless of what the corporation does with his money within legitimate limits, than there is in the case of the consumer? If the argument is to be that the funds are lying idle would it not be just as fair on the part of the corporation to say "Because the consumers' deposit will never have to be paid back in a lump sum, we will use them in our depreciа-

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tion reserve and since it is lying idle we will have to pay no interest on the deposits"? What a howl would go up!

To bring out the point still more clearly, refer again to Table V. Suppose that an appraisal were made in the twenty-first year when the property was in a 39 per cent condition. It would be unfair to base rates on the $9783 which is the corresponding value of the property, when it is known that as the renewals are made the per cent condition will go up as high as 68. Under this scheme the rates would depend entirely upon the condition of the property in the year it was appraised and there can be no question as to the unfairness of such a proceeding. The rates should be based on the depreciated value of the property in any year plus the amount in the depreciation reserve, provided only that the sum is not greater than the original capital expenditure.

In conclusion it may be said (1) No matter how large a property is, it will not necessarily come to any fixed per cent condition nor anywhere near it. (2) The per cent condition of any property, the amount in the reserve fund, and the rise of the reserve fund depend upon the past, present, and future growth of the company, and that these conditions and their relations should be studied for any property whether a public utility or a private corporation. (3) Rates should be based upon the depreciated value of the property plus the amount in the depreciation reserve as long as the sum is not greater than one hundred per cent of the total capital investment.

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TEMPERATURE DISTRIBUTIONS IN ELECTRICAL MACHINERY

BY B. G. LAMME

ABSTRACT OF PAPER

The paper deals with certain fundamental principles governing heat distribution and temperature in electrical apparatus. The general problems of heat generation, heat flow and heat dissipation, upon which the resultant temperatures depend, are discussed at some length. The various paths of heat flow and the effects of the heat resistance of such paths are discussed. The effects of rapid heat flow on the equalization of the temperatures, and on their measurement, are considered briefly. Some of the fallacies in temperature guarantees and in temperature indications are pointed out. Some of the more common errors in the methods of measurement are described. In conclusion it is stated that no hard and fast rules can be made to cover the facts, except in a very general way, and that commercial temperature measurements should be considered as approximate, this being permissible because there is no sharply defined line between good and bad.

THE LAWS governing heat flow and temperature distribution are so similar, in many respects, to those governing electric current flow and electric potentials, that it is rather surprising that the former have received so little attention in comparison with the latter. Some of the laws of heat flow are so well recognized that their application to the problem of temperature distribution in electric apparatus should have been a leading feature in the early developments in such apparatus; whereas, on the contrary, it is only recently that very careful study has been made of such application.

One object of this paper is to indicate, in a comparatively simple manner, some of the conditions which fix the temperatures in different parts of electric apparatus. Before going into the general problem, certain simple conditions may be stated, such as:

1. The heat flow between two points is proportional to their temperature difference and to the heat resistance of the path or paths between them. Note the resemblance to Ohm's law.

As a corollary to the above, it should be evident that between

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two points at the same temperature, there should be no flow of heat.

2. The total temperature drop between any two points or media of different temperatures will be the same through all paths of heat flow.

3. There are no true non-conductors of heat, and, conversely, no perfect conductors.

4. Heat conduction and electric conduction bear some quantitative relation to each other, in the broad sense that all electric insulators are relatively poor heat conductors, while good electric conductors are correspondingly good heat conductors. There is apparently no rigid relation between the heat resistance and electric resistance of the various materials used in electric machinery, but the general relation holds and there are apparently no radical exceptions.

5. The rise in temperature at any point, due to generation of heat, is dependent (a) upon the total heat generated, and (b) upon the amount of heat which can be carried away along all available paths per degree of temperature difference. The temperature will rise until the heat dissipation equals the heat generation.

6. There are two ways to lessen the heat flow along any path. (a) By interposing higher heat resisting materials. (b) By lessening the temperature difference, as by raising the temperature of the part through which the heat is to be conducted. Conversely, the heat flow can be increased along any path by the use of better heat conducting materials, or by paths of lower heat resistance, and by lessening the temperature of any part to which the heat is to flow.

What makes the problem unduly complicated, in electrical machinery, is the fact that there are several different sources of heat generation, which may be, and often are, all active at the same time. Moreover, the heat losses may be distributed through the various heat conducting paths in such a way as to render any calculation very difficult and more or less inexact, except in a general way. For example, there is heat generated by losses in the copper conductors, obeying one law; while there is heat generated in the iron parts under a quite different law; and there may be heat generated by windage and friction, according to a third law. As these different losses may act in different parts of the heat conducting circuit, it should be evident that the problem of determining the exact heat distributions,

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and the temperature, is a very complex one. Such a determination is in the province of the expert analytical designer of such apparatus, but certain general conditions are of interest to all users of electric apparatus.

Consider first the general conditions of heat dissipation from an armature coil. In Fig. 1 is represented an armature slot with the surrounding iron, and with two separate "coils" per slot, as is now the most common practise. Let it be assumed that the point *a* represents the "hot spot", or part at highest temperature in the apparatus. The heat from this part can flow along two general paths, namely, longitudinally through the copper conductor itself to the end windings, and thence to the air, and

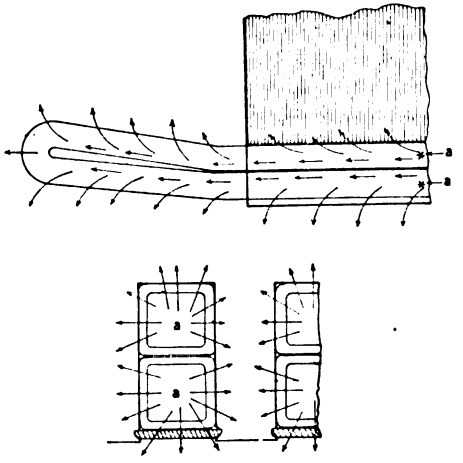

FIG. 1

laterally through the insulation to the surrounding iron, or to the ventilating ducts. From the iron the heat flow is then through various paths to the external cooling air.

LONGITUDINAL HEAT FLOW

Considering first the longitudinal conduction of heat in the coil, then starting at the point *a*, the first unit of length conductor will have a certain loss. If the heat generated by this first unit loss were all that need be considered, then the drop in temperature, from the point *a* to the end windings, would be simply a function of the heat-conducting properties of the conductor itself. But the next unit length is also generating its

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own unit loss, so that the heat flow from the second to the third unit length is due to two units loss; in the same way, the flow to the fourth unit length will be due to three units loss, etc. Therefore, the temperature drop, or temperature difference per unit length of conductor, increases more rapidly as the point *a* is departed from, and if it is at a considerable distance from the end winding, and the losses per unit length are comparatively high, a very high temperature may be required at *a* to conduct all the heat longitudinally to the end windings. In very wide core machines the longitudinal drop may be so great that the temperature at *a* in practise will be so far above that of the surrounding iron, that a very large percentage of the actual heat is conducted laterally through the insulation to the iron, even if the iron is at a comparatively high temperature. However, in narrow cores, the drop to the end windings may be, in some cases, so very low, possibly 5 to 10 degrees, that with good heat dissipation from the end windings themselves, the point *a* may have, for instance, an actual temperature of 40 deg. cent. If the iron next to *a* also has a temperature of 40 deg. cent. then there would be no flow of heat from *a* to the iron. Furthermore, in such a case, as the iron temperature over the whole width of the core may be fairly uniform, and as the copper temperature decreases from *a* to the end windings, obviously as we depart from the point *a*, there would be heat flow from the iron to the copper, and thus the windings would tend to cool the core. This is frequently the case with light loads on a machine, for in such conditions the coil loss is low, while the iron loss remains fairly constant for all loads. In such case there may be heat flow from the iron to the copper along the whole length of the buried portion of the coil. At some higher load, the copper loss varying as the square of the load, the increased longitudinal drop will bring the copper temperature above that of the iron so that the heat flow is from copper to iron. This condition is illustrated by Fig. 2.

It must be recognized that the lateral flow of heat, from the coil to the iron, reduces the longitudinal drop, such reduction depending upon the relative percentages of heat flow along the two paths. It must also be borne in mind that in order to have such longitudinal heat flow, the end windings must be able to dissipate their own heat at lower temperature than would be attained at *a*, or in the core. If the end windings have little or no ventilation, or heat dissipating capacity, then their own

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generated heat may bring their temperatures higher than those of the armature iron so that the heat flow actually may be from the end windings toward *a*, and then laterally through the insulation to the core. In such case, the hottest spot will be in the end winding rather than in the buried part of the coil. Obviously when such condition occurs there is no possibility of either the end windings or the buried part of the coil being cooler than the iron, for the heat flow throughout is toward the iron.

Lateral Heat Flow

Considering next the lateral flow of heat through the insulation to the iron, the amount of heat conducted is a function of the temperature difference and the resistance of the conducting path. Or, in other words, if a given amount of heat is to be conducted through a path of given resistance, the temperature in the heat generating part will rise until the required heat is conducted away.

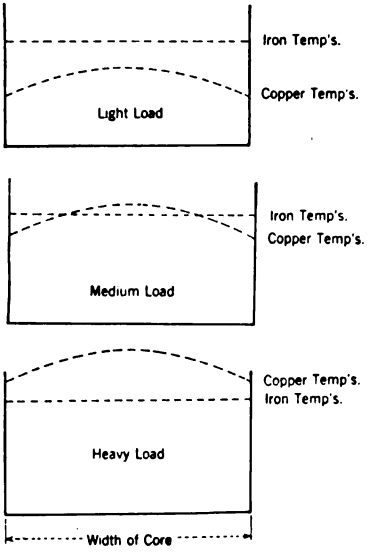

Fig. 2

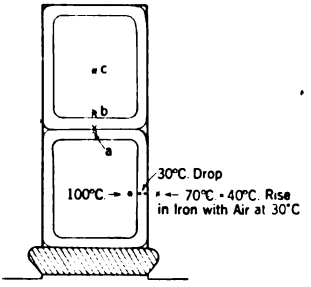

Fig. 3

To illustrate this problem more concretely, let Fig. 3 represent the temperature conditions in a section of an armature. Assuming, for example, the temperature of the copper inside the coil insulation as 100 deg. cent., the iron temperature as 70 deg. cent., and the air temperature as 30 deg. cent., then the following conclusions may be drawn.

(a) From the outer coil (the one next to the air gap) through the wedge to the air gap, the temperature drop will be 100 — 30 = 70 deg. cent. Obviously, any temperature measurement made outside the wedge, next to the air, will approximate the

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temperature of the air and not of the copper. Any temperature measurement made beneath the supporting wedge will measure some intermediate temperature between the copper and the air. If the temperature drop through the wedge should be equal to that through the insulation, then a measurement underneath the wedge should show half the temperature drop through insulation and wedge, and obviously, the measured temperature would be far below that of the copper.

(b) If the temperature is measured at the outside of the coil, between the iron and the insulation, it would approximate the average of the temperatures of the iron and of the outside insulation, or practically the temperature of the iron. If the iron should be at different temperatures at the sides of the slot and at the bottom, then obviously different readings would be obtained, depending upon the location of the measuring device. It is evident that such temperature measurements give no indication whatever as to the true internal temperatures of the coil, for the heat flow and the resistance of the insulation are nowise involved in the measurement.

(c) At a point *a*, between the two coils, there should be but little heat flow through the insulation, unless the copper is comparatively narrow. If there is but little heat flow through the insulation at this point, then eventually the temperature at the point *a* must rise to approximately that of the copper in the two coils. Therefore, a measuring device located at *a* will approximate the temperature of the copper itself, and is, in general, a good indication of the hot spot at that part of the winding. Therefore, as a practical method of temperature determination, a thermo-couple located at *a* is about the most satisfactory device that we have. However, the location of the point *a* along the slot is also of importance on account of the longitudinal flow of heat in the conductor and the consequent temperature drop. In other words, the direction of heat flow in the coil itself, must be taken into account. Therefore, a thermo-couple located as above, is only satisfactory when the general location of the hot spot is known beforehand. This is usually determined, in a general way, for a given type or line of machines, by locating several thermo-couples along the slots.

With narrow slots and comparatively thin conductors, and especially with very heavy insulation, there is some flow of heat through the insulation which lies between the two coils, this heat passing out sidewise to the iron. In such case, the point *a*

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may be of somewhat lower temperature than the copper. It may happen also, in some cases, that, due to unequal losses and heating of the two coils in the same slot, one is at a higher temperature than the other. In such case, due to the heat flow between the coils, the temperature indication at *a* will not show better than an average of the two temperatures. Furthermore, if the temperature at *c*, in a coil subdivided into many insulated conductors, is materially higher than at *b*, then the temperature indication at *a* may not be a close approximation to the maximum temperature.

Flow Through Iron Parts

In the ordinary armature, after the heat passes from the copper to the iron, there is still quite a problem involved in the dissipation to the surrounding medium, which is usually the air. The direction of the heat flow to the iron will depend, to a considerable extent, upon the arrangement and location of the heat dissipating surfaces. There are two general paths of heat conduction in all armature cores; namely, a flow along the laminations to where their edges come in contact with the air or with other material, and a flow across the laminations toward heat dissipating surfaces. The flow along the laminations may be calculated with fair accuracy. Across them it is difficult to determine such flow, largely because the laminations are insulated from each other by materials which are poor conductors of heat. Also such flow is affected not only by the insulation between laminations, but by the perfection of contact. In other words, the heat flow may be affected by pressure. According to the various figures available, the heat flow per unit volume of material along the laminations is from ten to one hundred times as great, for a given temperature difference, as across them. Obviously, therefore, heat dissipation from the iron by flow across the laminations should be considered relatively inefficient, yet in the vast majority of rotating machines the heat dissipation is largely across the laminations. The reason for this is that by placing ventilating passages or ducts, parallel with the laminations, at frequent intervals in the core, the cross section of the heat path in the intervening iron sections, may be made very large compared with the heat to be dissipated, so that the density of flow is very low. By the same procedure the length of the heat path is made quite short. Thus in practice, the temperature drop through the laminations themselves may be made relatively small compared with other drops. However,

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not all the heat in the iron passes across the laminations to the ventilating ducts, for where the length of the path, along the laminations to any heat dissipating surface, is not large, a very considerable amount of the heat may be dissipated from the edges of the laminations themselves. In fact, in certain types of machines with very shallow iron cores, experience has shown that the ventilating ducts, parallel with the laminations, may be omitted, provided good ventilation is obtained over the edges of the laminations. It is evident, therefore, that the flow of heat and distribution of temperature are dependent upon the arrangement of the iron, dimensions and location of the ventilating surfaces etc.

Heat Flow to the Air

After the heat has passed from the copper to the iron, the resultant of the copper and iron heats must be conducted to the cooling medium, which is usually the surrounding air. In the case of air, there is usually a considerable drop in temperature from the solid surface to the cooling air itself, the amount of such drop depending upon the ventilating conditions. In practise, there appears to be a film or layer of air which adheres very closely to the solid surfaces. This forms a sort of heat insulating film, retarding the flow of heat to the cooling air. In air ventilation, the effect of any considerable air movement over the surface appears to be that of scouring this hot film away from the surface and *replacing it with a film of cooler air.* Merely scouring or rubbing the hot film away from the surface is not particularly advantageous unless some means is furnished at the same time for supplying an ample quantity of cooler air to take the place of the removed hot film. Rapid air circulation, by means of a supply of air from the outside, appears to accomplish both results in one operation. Thus, one of the principal actions of air ventilation appears to be that of scouring away the hot contact film, while a second action is to carry the hot air away without mixing it with the incoming cooler air. Whatever portion of the dissipated heat is absorbed by the incoming cooling air adds that much to the temperature of the air itself and eventually to that of the apparatus to be cooled. Thus mixing the outgoing with the incoming air makes a sort of Siemens' regenerative furnace and the machine bocomes cumulatively hotter and hotter until the dissipation through other paths becomes equal to the heat generated. In such cases the ventilation

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of the machine may only be useful in equalizing or redistributing the temperatures in the various parts.

From the preceding analysis, it would appear that the temperature at the hottest part of the coil is fixed principally by the heat flow through the copper, and its surrounding insulation, directly to the air, and by the flow from the copper to the iron, and from the iron to any exposed air surfaces, and then to the air. Along the first path, there are three principal temperature drops; namely, in the copper itself, then through the insulation, and then from the outside surface of the insulation to the air. Along the second path, there are also three temperature drops; namely, from the copper through the insulation to the iron, then from the iron to the exposed air surfaces, and then from the surfaces to the air. Along the first path each part of the copper path is generating its own heat, to be conducted away, in addition to that which is to be conducted from other parts of the path. In the second path, each part of the iron path may be generating its own heat, which adds to that coming from other parts. The relative amount of heat conducted along each path is dependent upon so many conditions, which vary with the load, that no one but an analytical designer backed by experience could even approximate the values by calculation. However, it should be obvious that any measuring device applied to the outside or cooling surface does not, and cannot, directly approximate the temperature of the hottest part, except in those rare cases where the hottest part is dissipating heat directly to the air. This is true only in very special cases such as series coils of bare strap, etc. In any coil or part of the apparatus which is heavily insulated, that is, which is covered by poor heat conducting materials, an external temperature measurement is an extremely poor indication of the true internal temperature, unless many other conditions are known which may give an indication of the internal temperature drops. In different types and constructions of rotating apparatus, hot spots may hold quite different relative positions with respect to the cores and windings, so that no reasonable rule can be made to cover all cases. Moreover, in some classes of apparatus, it is not practicable to make any temperature measurements until after the apparatus is shut down, and this introduces other very important errors which should be considered, such as cooling effects as a whole, during the period of shut-down, equalization of temperature due to internal conduction, etc.

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EQUALIZATION OF TEMPERATURE, ETC.

When there are hot spots, or zones, or areas, of different temperatures, in an armature winding, for instance, such difference in temperature is maintained by the continual generation of heat in the various parts. But the moment that such generation of heat is stopped there is immediately a tendency for equalization of temperatures by flow of the stored heat from the hotter parts to the cooler. In good heat conducting materials, as copper, such equalization may be very rapid, so that a temperature indicating instrument of a sluggish type may not indicate anything like the true maximum temperature of the spot where it is placed, if applied after the load is removed, especially if the rate of heating of the thermometer bulb is much less than the rate of heat transfer from one part of the winding to another. If located on a hot spot, the reading may rise to some intermediate value and then drop off as the hot spot cools by heat conduction to other parts. If located upon a cool spot, it may rise slowly for a considerable period, due partly to sluggishness of the thermometer and partly to the cool spot rising in temperature by conduction of heat from some other part. The conditions are so varied that no reliable conclusions can be drawn, from the action of the thermometer alone, in regard to the coolest or hottest spot.

A second condition which tends to make such temperature measurements fallacious, lies in the cooling action in the interval between load removal and shut-down to take temperature measurements. In apparatus which depends upon a high degree of artificial cooling, such cooling effect may be very considerable. This is particularly true of high speed machines which require considerable time to come to a standstill. It is, therefore, desirable in such machines to obtain all possible temperature readings at normal speed and with load. In rotating field machines, this is, to a certain extent, practicable, but in most rotating armature machines, the armature temperatures usually are not attainable until the machine is brought to a standstill, and even then some error may result from sluggishness or delay in taking the readings. One method which has been proposed at times, for lessening the sluggishness, is to heat the thermometers up to practically the normal operating temperature of the part to be measured, while the machine is still carrying load. At the moment of shut-down the heated thermometer is applied. This, to a certain extent, removes the factor of sluggishness in the ther-

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mometer itself, but is only a partial compensation. It must be considered that the outside of the insulation is at lower temperature than the inside, and that, therefore, the body of the insulation itself must have its temperature increased by flow of heat from other parts.

Fallacies in Temperature Guarantees and Measurements

In the older methods of determining temperatures, it was assumed that the thermometer readings, obtained on a winding, for instance, was a true indication of the temperature of the winding as a whole. The manufacturers of electrical apparatus long ago recognized the fallacy of this method, as they had found from bitter experience that there were liable to be hotter parts in the machine than any thermometer readings would indicate. They, therefore, designed machines with regard to the possible hot spot temperatures as encountered in service, rather than any temperature which the exposed parts of the machine would show. Thus in designing a certain machine for safety at the hottest part, not infrequently the exposed parts of the winding would show, by thermometer, comparatively low temperatures, such as 25 deg. to 35 deg cent. rise. Therefore, as the observable temperature readings came so low it became the fashion to call for 35 deg. cent. guarantees and, in many cases, the operating public lost sight of, or perhaps never knew, the real meaning of such low temperatures. Among the designers of electrical machinery, it was recognized that a temperature rise of 35 deg. cent. in itself was absurdly low, but that the object in operating at such low temperature on a part which could be measured was simply to protect the machine in some inaccessible hotter part, where the temperature could not be measured. From the present viewpoint, it is astonishing what reliance has been placed upon temperature readings in the past. For example, if a 40 deg. cent. machine showed 41.5 deg. cent. rise on test, it was unsafe, while if it showed 38.5 deg. cent. rise, it was good. We now recognize that neither of these temperatures have any controlling value, unless many other conditions are known. To the experienced man they simply mean that compared with the other machines of similar constructions and characteristics, which have proved satisfactory in service, they are reasonably safe. To the designer they mean that when proper corrections have been made for the various internal temperature drops, the highest temperature attained, at any point, will be within the limits of

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durability of the insulating material used. The whole problem is a good deal like that of a determination of the voltage generated in a given power-house, by measuring the voltage at the end of a transmission-line. If we know all the constants of the line, and know the current flowing, etc., we can figure back to the generated voltage. Otherwise the voltage at the end of the line means but little. However, we know that if the system is designed with reasonable regard to economy in general, there may be from ten to twenty per cent voltage drop from power-house to the end of the line. Therefore, by adding an approximate correcting factor to this voltage, we can make a reasonable estimate of the generated voltage. In the same way in electrical apparatus of certain types, a reasonable internal temperature drop may be approximated, which added to the observable temperature, gives a fair approximation to the hottest part, but *the result is an approximation and must be recognized as such.* Primarily, the manufacturer must make a safe machine for a specified service regardless of the temperature guarantees, and the temperature measurements made on most classes of apparatus should be considered simply as rough approximations to indicate that the manufacturer has made a reasonable attempt at a safe machine. This may seem a rather bald statement, but nevertheless it is a fair statement of the case.

Errors in Temperature Measurement

It has been shown in the preceding that the usual observable temperatures are in most cases only crude approximations to the real temperature conditions. It may now be shown that even the observable temperatures, obtained by the usual means, are in themselves only crude approximations, in many cases. Take, for instance, the determination of temperature by increase in resistance; when the coil is heated its temperature may not be, and very frequently is not, uniform throughout the coil. As an extreme example, if one-fifth of the coil length has a temperature of 80 deg. cent., while four-fifths of it has a rise of 30 deg. cent. then the increase in resistance of the coil as a whole will correspond to a rise of 40 deg. cent. Thus, by increase of resistance, the temperature may be more than safe, while actually one-fifth of the coil is far above the safe temperature for ordinary fibrous insulations. In other words, the resistance method gives only average results and may be very misleading. However, in those cases where it is known, by past experience

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and otherwise, that there is very little liability of hot-spots, the resistance method of determining temperature is often quite satisfactory. However, the method is limited to comparatively few types of windings.

Considering next the thermometer method of measurement, the theory of this is quite simple, but apparently it has been very much misunderstood. In windings, except in rare cases, the thermometer is not applied directly to the heat generating material itself, but is applied outside of an insulating covering. Usually the temperature drop through this insulating covering does not receive any consideration, and yet everything depends upon this. Assume, for example, an insulated coil, thermometer and covering pad, as shown in Fig. 4. Assuming the copper inside the coil as being of uniform temperature, and the cooling air at *a* and *b* as also at a uniform, but much lower, temperature than inside the coil; then the temperature drop from the copper to *b* will be the same as through the insulation, thermometer

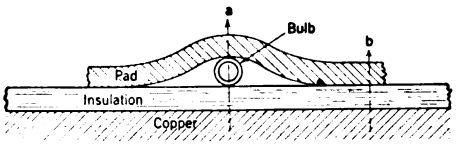

FIG. 4

bulb and covering pad to the air at *a*. Obviously if the temperature drops through the insulation and through the pad are equal, then the thermometer bulb will show a midway temperature. This is, of course, assuming that the surface drop to the air, previously referred to, is very small, or that it is included as part of the drop through the pad. Obviously, if the drop through the covering pad is made very much higher than that through the insulation proper, then the thermometer bulb more closely approaches the copper temperature. Thus it is seen that all kinds of results may be obtained, depending upon the relative drops through the pad and through the insulation. In a low voltage machine, with relatively thin insulation, the pad may take most of the drop. With very heavy insulation, the pad may take proportionately less and the thermometer reading departs accordingly from the copper temperature. It might be suggested that a big thick pad of very poor heat conducting material might be used. This apparently would tend toward more ac-

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curate temperature readings, but, on the other hand, harmful effects may be introduced by the use of a large pad. The resistance to heat dissipation being increased in the area covered by the pad, obviously less heat will be carried away at this point and, therefore, the heat generated under the pad must be conducted to adjacent parts of the coil. This means an increased temperature at this point, due to the use of the pad. Again, the use of the pad, in some cases, may affect the normal ventilation of certain parts of the coil not directly covered by the pad. For instance, if there is a ventilating space between two adjacent armature coils, through which air is normally driven, a pad which covers this space even partially may create more or less of an air pocket, and thus materially affect the heat dissipation, and the temperature directly under the pad. Experience has shown that both of the above conditions are obtained when good judgment is not used in the application of the covering pad. This, of course, applies particularly to those cases where temperature readings are obtained while the machine is in operation. Of course, after shut-down, most questions of ventilation and of generation of higher temperature under the pad need not be taken into account.

There are so many conditions entering into the interpretation of the thermometer and resistance methods of determining temperature, that in certain classes of apparatus it has been very desirable to find more accurate methods. One of these is in the use of so called resistance coils. In this method a coil of fine wire of a known temperature co-efficient, and of known resistance at a given temperature, is placed at the place where the temperature is to be measured, and the temperature rise is determined from the increased resistance of the coil. One serious objection to this arrangement, is that the resistance coil must have considerable length and breadth so that it really indicates the average temperature of a considerable area instead of a point. When placed between two coils, as indicated in Fig. 5, it usually occupies so great a proportion of the slot that it indicates an average temperature considerably lower than at *a*. Furthermore, on account of the length of such coils, there may be a considerable difference between the temperatures at the two ends. Thus the resistance coil, like the resistance measurement of the windings themselves, gives an average result, but this average may be limited to a comparatively small area, whereas, in the resistance method in general the indicated rise is an average of the whole winding. However, in the resistance method, the tem-

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perature of the conductors themselves is measured, whereas, with the resistance coil the temperature measurement is outside the insulation. The resistance coil method is, therefore, a relatively crude approximation, although when brought out it was really an important step in advance. In its early application, many misleading results were obtained, due largely to lack of understanding of the principles governing temperature distribution and temperature drop. In some cases, the resistance coil was placed under the wedge as at *b* in Fig. 5. In other cases, the coil was placed at the side of the slot next to the iron, or at the bottom. Very rarely was it placed midway between the two coils, probably because this was a more difficult application and

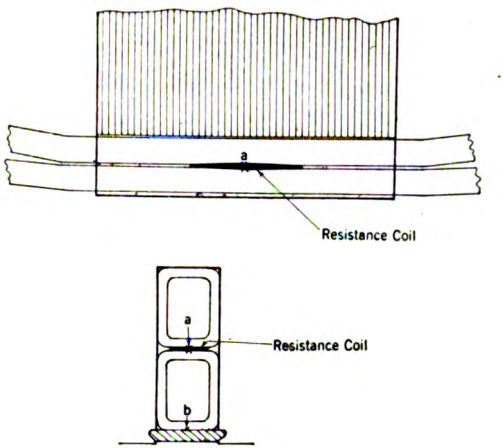

FIG. 5

also because the greater accuracy of such location was not recognized. From the use of resistance coils many good engineers drew the conclusions that the upper limit of permissible temperature for fibrous insulations was only 80 deg. to 90 deg. cent., because with the coils located in certain ways and places, deterioration of insulation at some other point was liable to begin, if the above temperatures were exceeded. The error was in not recognizing the temperature drop between some hotter spot and the average location of the resistance coil. When this condition was recognized, the results obtained by resistance coils became more consistent with the facts.

A later development than the resistance coil is the thermocouple as a practical device for measuring temperature. One

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great advantage of the thermo-couple is its very small size, so that it can indicate the temperature at practically a point instead of a very considerable area. Moreover, as it is a zero current method of measurement, when used with a potentiometer no question of size or length of the connecting leads need come up. The thermo-couple is so small and has so little mass, that it can follow very quickly any temperature changes where it is located. If properly placed it furnishes the most accurate temperature indicator which we now have, as it can be located in all sorts of normally inaccessible places. However, its use is practically limited to stationary apparatus. In rotating apparatus, or rotating parts it can be used only after shut-down, which introduces errors, as already shown.

Many-Conductor Coils

In all the preceding considerations it has been assumed that the copper inside the coils itself is at a uniform temperature, in any given unit of length. This is practically true, provided the coil is made up of a single conductor, or of a relatively few conductors with only a moderate amount of insulation between them When several coils or conductors are placed side by side, as in Fig. 6, it would appear at first glance that the middle coils should heat much more than the outer ones. But, in reality, unless there are many layers of coils, the temperatures of the different coils will not vary greatly from each other. For instance, in Fig. 6, the heat generated in the middle conductor is only one-third that of the total generated in the coil, and yet the two side surfaces through which this heat passes to the adjacent coils aggregate almost as much as the total outside dissipating surface of the whole coil, through which all the lateral heat flow is dissipated. Considering further that the insulation between the middle coil and its neighbors is relatively thin compared with the outside covering, it is obvious that the temperature drop from this coil to the adjacent ones will be comparatively small,—possibly not over ten per cent of the drop through the outside insulation.

However, with a large number of coils side by side, the conditions become cumulatively worse. Here, the drop from the center conductor to the next one, may be small. But the drop from the second conductor to the third is considerably greater due to the heat of two conductors being transmitted. From the third to the fourth there is a drop corresponding to the losses

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of three conductors, etc. Thus, there is a gradually increasing temperature drop from the center of the coil toward the outside surface, and if the coil be very deep, that is, if it consists of many insulated layers, the sum total of the drops may be quite large. Or, putting it in another way, with a comparatively deep coil, the temperature rise from the outside surface of the coil itself toward the center will be very rapid at first, and gradually taper off, as indicated in Fig. 7. This is indicated very clearly in the case of an over-heated field of coil of fine wire. Here the first outside layers will usually be found in a fairly good condition, but at a comparatively little distance inside the coil there may be severe roasting or evidence of overheating, which may be

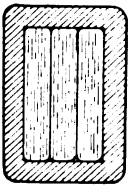

FIG. 6

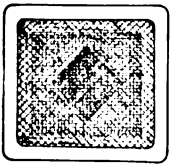

FIG. 8

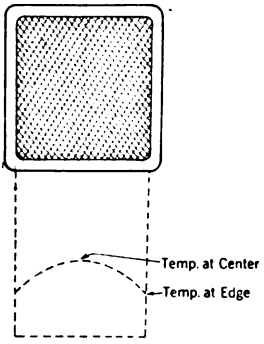

FIG. 7

almost as bad as at the center. (See Fig. 8.) In such case, the temperature measurement on the outside of the coil is no satisfactory indication of the hot-spot temperature. A temperature measurement by resistance, while a closer indication than that by thermometer, also may be very misleading. It may be stated that modern design tendencies are toward comparatively shallow field coils, largely on account of this condition.

CONCLUSION

The whole object of this paper is to show the problem of temperature distribution and temperature measurement, as it actually is. It is the writer's desire to show that no hard and fast rules can be made for determining the facts in the case, and that

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the best rules and methods now practicable are only approximate. The present limitations set for insulating materials are much higher than were considered practicable only a few years ago. This is not because the limits have been raised, but because, through a better understanding of the facts, the real upper limits of temperature as fixed by durability of insulation, are now known to be considerably higher than was believed to be the case only a short time ago. If the real limits were in accordance with former beliefs, then all the evidence of the more accurate modern tests and data would indicate that the vast majority of the existing electrical machines should have "roasted out" comparatively early in their operation. The higher temperature limits were there, but were not recognized. Now we recognize them and attempt to make reasonable allowances for differences between the measurable temperatures and the actual hottest parts. The present method may be crude, but we are not going at it blindly, as was formerly the case. Formerly the manufacturer took the real responsibility for making a machine that was safe for the service, whatever the guarantees called for. Today the responsibility is still his, but he is attempting to educate the public to a knowledge of his real problems, and to a recognition that temperature determination is far from being an exact art. There is no sharply defined line between *good* and *bad* in the insulating materials as affected by temperature, consequently there is no sharp line between *safe* and *unsafe* temperatures.

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To be presented at the Chicago Section meeting of the American Institute of Electrical Engineers, November 27, 1916.

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RATIONAL TEMPERATURE GUARANTEES FOR LARGE A-C. GENERATORS

BY F. D. NEWBURY

ABSTRACT OF PAPER

The paper is an argument for the standardization of temperature guarantees when the guarantee is based on internal temperatures as measured by thermo-couples. It is recommended that in all cases the maximum safe operating temperature of the insulation be used as the temperature guarantee, instead of using a lower temperature. The standardized guarantee, 50-deg. rise by thermometer, is cited in comparison with the present wide range of temperature rises, from 60 deg. to 100 deg., that have been called for in specifications when the thermo-couple method of measurement is used. Arguments are presented from the stand-point of both the designing and the operating engineer for the use of this standardized temperature rise. Curves are shown illustrating the temperature conditions in both stator and rotor of a typical large, high-voltage turbo-generator. Examples, based on these curves, are given to show that a low temperature rise guarantee for the stator does not necessarily result in margin for overloads. This margin for overloads is the main argument that can be advanced in favor of low temperature rises. The only way in which the purchaser can be certain of overload margin is to have the specifications call for the maximum rating desired, in which case the maximum safe operating temperature may logically be made the temperature guarantee.

OPERATING engineers are familiar with the use of a single standardized guarantee of temperature rise by thermometer for large single-rated generators, and particularly for turbo-generators. During the past five or ten years, such generators have been purchased very generally on the basis of a 50 deg. rise, measured by thermometer. This standard rise was fixed at 50 deg. because it was felt, by reason of general experience, that this represented the maximum safe rise. It was recognized that with guarantees based on the temperatures of external surfaces, a single limit could not be fixed that would fit all cases; yet a single limit was fixed and has been adhered to in practically all commercial transactions. This standardized guarantee, moreover, takes no cognizance of the inherent variations in the actual temperature performance of individual units. A high-voltage

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generator and a similar low-voltage generator under some conditions should be designed for quite different temperatures as measured by thermometer (on account of greater temperature drop due to thicker insulation with high voltage) yet both these units would be guaranteed for a rise of 50 deg. in accordance with this established practise.

In the commercial introduction of the thermo-couple or resistance-coil methods of measurement, as a basis for guarantees there has been a tendency to lose sight of this idea of a standardized guarantee. When this method first appeared in contracts about three years ago, guarantees for "hot-spot" rises as low as 40 deg. were required in some instances. As the real significance of the results obtained by these internal measurements became better known, the specified temperature rises based on this method have gradually increased up to the relatively high values consistent with the safe operating temperatures of mica insulation. With built-up mica insulation, a safe operating temperature of 150 deg. may be guaranteed, and the corresponding temperature rise guarantee may be 105 deg., or, in round numbers, 100 deg. Yet even today there is no uniformity in guarantees. Temperature rises of 60 deg. are often called for in specifications, even when mica insulation is employed, and practically all temperatures between 60 deg and 100 deg. have been used as guarantees on one occasion or another.

In discussing maximum permissible rises, the author has in mind the limits allowed when mica or other Class B insulations are used. The maximum safe rise allowed by Class A insulations is only 60 deg. and this is so near the familiar guarantee of 50 deg. rise by thermometer that there is no tendency to give guarantees below the possible maximum when this class of insulation is employed.

From the standpoint of the designer of large generators, the desirability of a standardized temperature guarantee that is consistent with the safe operating temperature of mica insulation is apparent. When other conditions permit, full advantage can be taken of the heat-resisting properties of the insulation and the most efficient and economical design can be produced. In the largest two- and four-pole generators, it is not only desirable, but in many cases it is necessary that such advantage be taken in order that the safest mechanical design may be produced. It is good common sense that the copper and the sheet steel cores be pushed to the limit, electrically and magnetically, so that

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greater factors of safety may be provided in the all-important mechanical features of the design. There are so many real limitations imposed by the physical characteristics of the available materials that demand careful consideration in the design of high speed machinery, that the imposition of additional "man-made" restrictions should by all means be avoided. They only serve to uselessly impede progress.

In a fair, sensible contract there should be no conflicting or inconsistent guarantees. It is now customary to include in many contracts for large generators a guarantee covering the total temperature that the insulation will continuously withstand without injury. Such a guarantee of the insulation is virtually a guarantee of maximum capacity—so far as capacity is determined by heating—and so covers, broadly, the same ground as the guarantee of temperature rise. Obviously, the two guarantees should be equivalent. An example will make this clear. With suitable mica insulation, 150 deg. is frequently used as the safe limiting temperature guarantee. Assume that this guarantee is made and also that the generator is guaranteed to deliver its rated kilovolt-amperes without exceeding a temperature rise of 80 deg. Two different guarantees will have been made; one that the generator will deliver its guaranteed load with a total existing temperature of 125 deg. (adding 40 deg. air temperature and 5 deg. allowance to the guaranteed rise in accordance with the A. I. E. E. Standardization Rules); and another that the generator can be safely operated up to a temperature of 150 deg. The guaranteed temperature rise should have been 105 deg. to make the two guarantees consistent and rational.

In considering the subject of low versus high temperature rise guarantees, one is apt to look upon a low rise in itself as an advantage just as low loss in a generator is an advantage. A temperature rise guarantee, however, is radically different in nature from a loss or efficiency guarantee. In the case of efficiency the operator is interested in what the apparatus will actually do; any reduction in losses is of direct benefit, and the greater the reduction, the better will be the generator. With temperature, on the other hand, the operator is only interested in temperature rise to the extent of knowing that it is safe; he is not primarily interested in temperature figures. If the operating temperature is safe, a lower temperature will be no safer and of no particular value.

The importance to the operator of a temperature guarantee

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lower than that permitted by the characteristics of the materials is frequently over-estimated. It is felt, naturally enough, that this margin permits the generator to safely carry heavier loads than contracted for or to safely operate under abnormal conditions in emergency. The fact that the value of the guaranteed safe limiting temperature is based on continuous service gives sufficient margin for emergencies. For limited periods—and this can safely amount to months of service in the aggregate—considerably higher temperatures are permissible, and this margin will cover any probable combination of emergencies. A completely mica-insulated generator has seldom, if ever, failed on account of insulation breakdown due to excessive loading in emergency. The limiting load is usually reached because of some other factor, such as turbine capacity, ability to maintain voltage, etc.

It may still be argued that a low stator rise is desirable on account of the margin it gives for continuous overloads. There would be a better basis for this argument if an equal margin were provided in the design of the generator in all other respects —in rotor heating and exciting voltage particularly. But this is seldom, if ever, done. While practice in stator temperature rise guarantees is still somewhat unsettled, the practise in rotor temperature rise guarantees is pretty well fixed. For the generators under consideration, a rotor rise in the neighborhood of 100 deg. by resistance at the maximum rating is well established. Thus, even if a rise as low as 60 deg. be guaranteed for the stator, a rise of 100 deg. is often given for the rotor of the same generator. This at once makes it impracticable to take advantage of the assumed reserve capacity of the stator. Any increase in load, resulting in an increase in the temperature of the armature winding will cause a much greater increase in field winding temperature and voltage drop with this initial field temperature. Consequently, if an overload is contemplated, the temperature rise of the field winding at the nominal load should be approximately the same as that of the armature winding.

Some fundamental relations in large turbo generators are illustrated by the Curves, Figs. 1, 2, and 3. These curves will be used to explain, among other things, the above statement. Fig. 1 shows the variation of armature temperature rise with changes in load on the basis of 100 deg. rise at 100 per cent load. The rises in different parts of the stator are shown by the several curves. These curves are based on careful factory tests of various

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generators, approximating 20,000 kv-a., at 1800 rev. per min. and 13,000 volts. They may be considered as typical of the large, high-speed, high-voltage generator. Temperature tests were made at normal voltage and open circuit and at normal voltage and at various percentages of rated load. The temperatures at other than tested loads are taken as proportional to the losses involved. In the case of the cooling air, the temperature rise varies in proportion to the total losses of the generator; in the core, the temperature drop varies with the total stator losses (neglecting the relatively small loss dissipated through the coil ends); and in the case of the winding, the temperature drop through the insulation varies with the total loss in the embedded copper. These curves are only roughly approximate but are sufficiently accurate for the present purpose. They give a picture of the temperature conditions in the stator of many of the large high-voltage turbo-generators that have been placed in operation during the past three years.

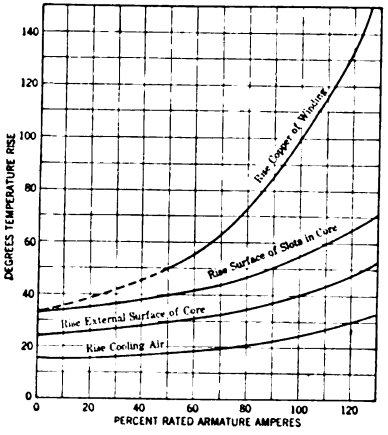

FIG. 1—TEMPERATURE CONDITIONS IN LARGE TURBO-GENERATOR STATORS

According to these curves, in such a turbo generator, at 100 per cent of rated load, the cooling air rises 25 deg.; the outside surface of the core rises 40 deg. above the entering air, or 15 deg. above the temperature of the discharge air in contact with this surface. There is a drop of 45 deg. through the armature coil insulation, giving the total rise of 100 deg. in the copper. It will be noted that nearly half of this total rise is accounted for by the temperature drop through the insulation and consequently, any material reduction in the total rise must involve a substantial reduction in the temperature drop through the insulation. In considering these curves it must be borne in mind that they represent the average generator of a particular class and are based on generators designed to operate at 100 deg. rise in the stator copper at rated load.

On account of its importance, it is well, at this point to consider in detail the reasons for this relatively large temperature drop

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through the coil insulation and the factors that determine it. The temperature drop through the insulation is probably the most important single item in determining the copper temperature and is directly responsible for the greater part of the difference between temperature measured by mercury thermometers placed outside of the insulation on the coil ends and by thermocouples placed so as to approximately measure the true copper temperature.

The general principles on which differences between internal and external temperatures depend have been explained in the paper by Mr. Lamme, on *Temperature Distribution in Electrical Machinery*, and need not be given here. The particular points that apply to the present problem may, however, be briefly stated.

The most important path of heat flow in the stator of a generator having a long core is in the plane of the laminations, that is, from the copper of an armature coil, through the insulation, and through the sheet steel of the core to the air. The most important part of this path is the insulation. As Mr. Lamme points out, the temperature drop through the insulation is proportional to the heat transmitted (watts loss) to the length of the path (the thickness of the insulation) to the cross sectional area of the path (the surface of the insulation in contact with the core laminations) and the heat resistance of the material.

A measure of the resistance to the flow of heat, or, more properly, a measure of the thermal conductivity, is that rate of heat flow, expressed in watts, that will cause a drop of one deg. cent. when transmitted through an inch length and a square inch section of the material; just as in the electric circuit the conductivity might be expressed as the value of current flow that will cause one volt drop through an inch cube of the material. Values of thermal conductivity of composite forms of insulation are difficult to determine because different samples, apparently similar, give widely differing results. This is largely due to the effect of air pockets in the insulation. The tighter the insulation, the higher will be the conductivity. For example, in tests made by Symonds and Walker*, solid mica was found to have a thermal conductivity of 0.00915 watts per inch cube, while built up mica coil insulation had a conductivity less than one-third of this. Glass (to consider another solid ordinarily

*"Heat Paths in Electrical Machinery", Harold D. Symonds and Miles Walker, *Journal I. E. E.*, Vol. XLVIII, 1912, p. 674.

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thought of as a poor heat conductor) is about ten times as good a conductor as the usual coil insulations. It is safe to say that the degree to which air spaces exist in the insulation has more influence on the heat conductivity than does any difference there may be in the conductivities of the various component materials such as paper, cloth, varnish, mica, etc., From the best data available it appears that the heat conductivity of coil insulations, commonly used, varies from 0.0025 to 0.005 watts per inch cube of the material; the lower range of figures applies to the older hand-wrapped materials while the higher range covers insulation applied under heat and heavy pressure by machinery. From the standpoint of heat conductivity and temperature drop the importance of tightly wrapped, compact insulation is obviously very great.

When the rate of heat flow, expressed in watts, and the thermal conductivity and dimensions of the insulation are known it is possible to calculate the temperature drop through the insulation with a fair degree of accuracy. The determination of the rate of heat flow, however, involves two factors that require considerable experience to estimate; one, the proportions of the total heat that are transmitted along the copper to the coil ends and through the insulation to the core; and, the other, the increase in loss due to eddy currents in the copper.* Since the present purpose is only to show the order of magnitude of this drop and the reasonableness of the figure given for the typical generator in Fig. 1, it will be sufficiently accurate to assume that one factor offsets the other; that the eddy current losses are equal to the loss transmitted longitudinally through the copper. It will also be assumed that the insulation is as compact as it is possible to make it and has a thermal conductivity (including the air space† between the coil and slot) of 0.0035 watts. It is usual in units of this class to work the copper in the neighborhood of 1600 amperes per sq. in. which results with slots of usual

*It is interesting to note that the eddy current loss in the copper, in a well designed generator is only a small part of the load loss measured with the generator short-circuited, and that there is no method, so far as the writer knows, of accurately calculating this loss. The theory and formula developed by Field, Rogowski and others only cover the limiting cases of solid conductors or infinitely laminated conductors.

†Still air has a thermal conductivity only one-tenth that of built up insulations. Even with the closest possible fit between the coil and the laminations, which present a more or less rough surface to the coil, there is an appreciable decrease in the conductivity due to this "joint."

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proportions, in a loss (considering only I^2R loss at the operating temperature as previously explained) of 0.6 watts per square inch of insulation surface. For 11,000 or 13,200 volts, a reasonable thickness of insulation from copper to core may be taken at 0.25 inch. Using these figures the temperature drop may be calculated thus:

Thermal drop (in deg. cent).

$$= \frac{\text{Watts} \times \text{thickness of insulation (inches)}}{\text{Surface of insulation (sq. in.)} \times \text{thermal conductivity}}$$

or:

$$\text{Thermal drop} = \frac{0.6 \times 0.25}{0.0035} = 43 \text{ deg. cent.}$$

This checks with the 45 deg. used in the typical curve.

It is apparent that this drop can be reduced by decreasing the watts per sq. in. (by decreasing the current density or increasing the slot surface or by both) by decreasing the thickness of the insulation or by improving its thermal conductivity.

With existing insulating materials and methods it is not feasible to materially reduce this temperature drop by these latter methods. Neither can the slot surface be materially increased nor the current density be reduced except by correspondingly increasing the dimensions of the stator, and this may be undesirable or even impracticable in the largest two- and four-pole generators on account of mechanical limitations.

The thickness of the insulation and therefore the thermal drop is a direct function of the rated voltage. At 2400 volts for example, the thickness of insulation and the drop are roughly half the corresponding figures for 11,000 volts. While it is generally recognized that the internal temperatures in high-voltage generators are greater than in low-voltage generators for equal surface temperatures, it is, perhaps, not so generally appreciated that the temperature drop varies so directly with the thickness of insulation and amounts to such a large figure.

This question of temperature drop through the insulation has been considered somewhat in length because it is the most important single factor in determining the hot-spot temperature in large high-voltage, high-speed generators. If the magnitude of the temperature drop through the insulation is recognized, the difference between a 50 deg. guarantee by thermometer and a 100 deg. guarantee by a properly placed thermo couple is immed-

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iately explained. It will be noted that in the typical generator, illustrated by Fig. 1, the temperature rise of the core surface is only 40 deg. and the temperature rise of the exposed end windings would be in the neighborhood of 50 deg. using ordinary methods of applying thermometers. In other words, this generator which has a hot-spot temperature rise of 100 deg. would probably meet a 50 deg. rise guarantee based on surface temperatures.

Fig. 2 shows the increase in field temperature and voltage drop with increase in field current. The temperature curve is based on the assumption that the temperature rise at rated load is 100 deg. and is proportional to the loss at other loads. The loss and temperature rise increase considerably faster than in proportion to the square of the current, due to the increase in resistance with temperature. This factor becomes of very great importance at the relatively high temperatures at which turbo fields are ordinarily worked. Thus, with a 10 per cent increase in field current, above 100 per cent of rated current, the temperature rise increases 33 per cent, where only 21 per cent would have resulted if the resistance had remained constant. Due to this effect and also to the second-power relation between the current and loss, the temperature rise increases at a greatly accelerated rate for current above normal. For example; the first 100 deg. of rise is produced by 100 per cent of normal full-load field amperes; the second 100 deg. rise is produced by an additional 25 per cent of normal amperes; and the third 100 deg. of rise is produced by only 15 per cent of normal amperes. In other words, to obtain an increase of 40 per cent in ampere turns, the loss must be tripled and the temperature rise must be increased from 100 deg. to 300 deg. There is also a correspondingly rapid increase in required exciting voltage for field

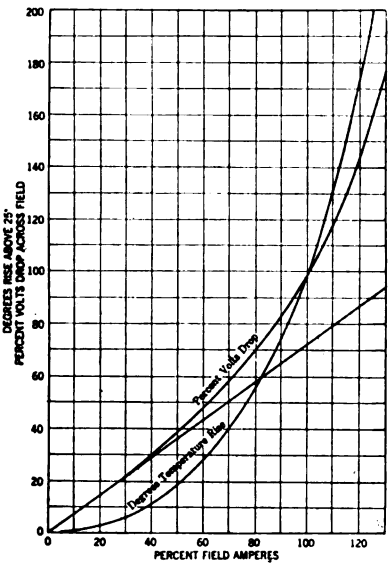

FIG. 2—TEMPERATURE RISE AND VOLTS DROP IN LARGE TURBO-GENERATOR ROTORS

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currents above normal. Even though the drop increases only in proportion to the first power of the current, the further increase due to the increase in resistance makes the total rate nearly as great as in the case of the loss and temperature rise. The drop on the basis of constant resistance is shown by the straight line in Fig. 2. The difference in the ordinate of this straight line and the total drop shows graphically the large effect of the change in resistance at currents above normal. To obtain only 25 per cent increase in exciting ampere-turns, an increase of 60 per cent in exciting voltage is demanded. This increase in exciting voltage is, in the majority of mica insulated generators, the real limit to overload capacity. The insulation used in the rotors of large turbo-generators with which the author is familiar is solid molded mica between the copper and ground, and mica and asbestos tape between turns. Such insulation can obviously withstand temperatures of several hundred degrees, yet the total temperature is limited to 150 degrees, on account of the prohibitive increase in exciting voltage, just described, that occurs with higher temperatures. Thus, so far as the rotor is concerned, temperature is not directly a limit to capacity.

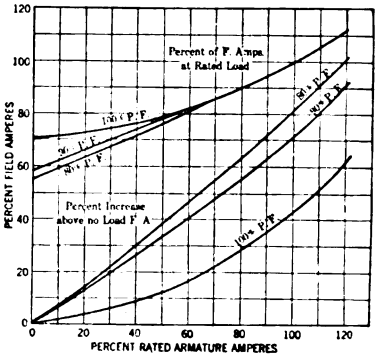

FIG. 3—RELATION BETWEEN ARMATURE CURRENT AND FIELD CURRENT IN LARGE TURBO-GENERATORS. RATIO OF FIELD AMPERES TO GENERATE NORMAL VOLTS ON OPEN CIRCUIT TO FIELD AMPERES TO CIRCULATE NORMAL ARMATURE AMPERES ON SHORT CIRCUIT EQUALLING 1.00

Fig. 3 shows the relation between armature amperes and field amperes in a large turbo-generator of average design proportions, and ties together the data given in Figs. 1 and 2. While differences between individual units will change this relation to some extent, the change will not be of such magnitude as to affect the conclusions reached. The three lower curves show the *increase in field current above the no-load value* for different power factors. In the upper curves this same data has been expressed as the *percentage of the full-load field amperes* at each of the three power factors. These curves show that in three different generators, one designed for 100 per cent power factor operation, a

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second for 90 per cent power factor, and the third for 80 per cent power factor, all having the same ratio between armature and field strengths, the increase in field current expressed as a percentage of full-load field current will be the same between 70 per cent and 120 per cent of rated load. For the present purpose, operating power factor may therefore be disregarded, *providing the generator is assumed to operate at the power factor for which it was designed.*

These curves may now be used to prove the statement, previously made, that, in order to provide additional capacity in a generator beyond the contract rating it is necessary that the temperature rise guarantees of the armature winding and of the field winding be approximately equal. If a generator has a true hot-spot rise of 60 deg. in the stator and a rise by resistance of 100 deg. on the rotor the promise of margin for overloads given by the low armature temperature will prove to be fruitless. To restate this in the words of the original proposition; a low stator rise does not guarantee margin for overloads.

The question will be considered in two ways; first, to show what field winding temperature rise and exciting voltage are consistent with an armature temperature rise of 60 deg.; and second, to show what field winding temperature rise and exciting voltage will result when the load is increased so as to increase a low armature temperature rise to the safe operating temperature with a generator having an initial field temperature rise of 100 deg.

Let it be assumed that a purchaser believes more margin in stator temperature rise is desirable in order to obtain margin in capacity for contingencies, and specifies that the stator temperature rise as measured by thermo-couple shall not exceed 60 deg. What rotor temperature rise and what margin in exciting voltage should be specified in order that this expected margin may be realized? This condition requires that a consistently designed generator be assumed; that is, a generator capable of operating at the anticipated maximum load within the guaranteed safe limiting temperature of the insulation in both armature and field, and requiring an exciting voltage within that available, or, in other words, a generator having characteristics shown in Figs. 1, 2, and 3, at the maximum expected rating. This generator, as illustrated by Fig. 1, must be derated from 100 per cent to 66 per cent rating to meet 60 deg. rise in the stator, so that a high, voltage generator, of these relative core and cop-

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per temperatures, that meets 60 deg. rise at its nameplate rating, can carry 50 per cent overload continuously, and still operate within the safe temperature of mica insulation. The relative core and copper temperatures may be varied somewhat in different designs, but on account of the magnitude of the core loss and windage loss, as compared with the stator copper loss, the feasible variation is not large.

From Fig. 3, 66 per cent of rated armature amperes requires 84 per cent of the field excitation at 100 per cent load. From Fig. 2, the temperature and exciting voltage at 84 per cent field excitation are 64 deg. and 76 per cent respectively. Thus, consistent guarantees would be 60 deg. by thermo-couple, for the armature, and 60 deg. by resistance for the field winding, and the generator should be designed to require not more than 90 volts exciting voltage (on the basis of 125 volts available). In taking the required field current at the nameplate rating from 66 per cent rating on Fig. 3, we have, in effect, maintained the assumed unity relation between armature and field strengths at the capacity rating. This results in a ratio of 1.5 at the nameplate rating, which is a higher ratio than would probably be used for a large two- or four-pole turbo-generator. In other words, in an actual design, the field would be relatively weaker than in the above case, and the increase in field current, temperature, and exciting voltage, would be greater than in the example and the guaranteed figures for the rotor should be correspondingly lowered. To complete the story, then, this ratio or an equivalent design figure, must also be specified.

The determination of consistent guarantees that will make certain a desired margin in generator capacity, no doubt appears, from this example, to be a complicated matter. It is, if the purchaser attempts to secure margin in capacity in this indirect fashion. If this margin is really desired, the purchaser should make the desired maximum rating and the contract rating the same, when all these difficulties will disappear. The low temperature rises will, incidently, also disappear from the contract.

To illustrate the second form of this question, assume that a generator has been purchased on the basis of a stator rise of 60 deg. by thermo-couple and a rotor rise of 100 deg. by resistance. It is assumed that both armature and field are mica-insulated. Thus there is a margin in capacity in the armature equal to 50 per cent of its rating, while there is no margin, on

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the basis of the guarantees, in the field. If the load were increased to the limit of the armature, there would result a temperature rise in the neighborhood of 400 deg. in the field, and an exciting voltage would be required nearly three times normal. Of course, these are impossible operating conditions;— with these assumed rises of 60 deg. and 100 deg. there is no possibility of taking advantage of the low armature temperature. Consider then a less extreme case. Let the armature rise be 80 deg. when the field rise is 100 deg. Then an increase in load of 16 per cent (from 86 per cent to 100 per cent, Fig. 1) is permissible, without exceeding the limiting safe rise of 100 deg. This requires an increase of 9 per cent in field excitation (Fig. 3); and results in a rise of 130 deg. and a voltage drop across the field winding of 117 per cent. This would require an exciter voltage of approximately 150 volts on the basis of 125 volt excitation.

These examples illustrate the point already made, that a low temperature rise guarantee for the armature is not in itself a guarantee of operating margin; that the only way in which this margin can be surely obtained is for the purchaser to draw his specifications for the maximum rating desired. Obviously, at this maximum rating the maximum safe temperature rise may be used.

After all is said, the demand for low temperature guarantees usually has back of it a skepticism as to the real safety of the limiting temperature claimed for the insulating materials. Operating engineers may safely leave this question with the designers. In this particular field of design, assumed limits are being continually exceeded and extended. New designs are, from necessity, based on an experimental study of materials and on an analysis of constructions and of complex phenomena involved in the operation of the generator to a greater extent than on direct experience with similar machines. On no other basis could sizes of high-speed units have been increased in single steps from 10,000 kv-a. to 20,000 kv-a. or from 35,000 kv-a. to 50,000 kv-a. Under these conditions, the guarantees made in the contract are really of secondary importance as compared with the ability and experience of the designers. The situation is quite different from that existing with smaller medium-speed machines where the temperature and other guarantees are, in many cases, the operators's principal safeguard. With these large turbine units, each one representing an investment of

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several hundred thousand dollars, the designer must be conservative; chances cannot knowingly be taken. Whether the temperature rise guarantee is 100 deg. or 50 deg., or, if in the future it should become 150 deg., the engineering public may rest assured that, everything considered, it is conservative. Those responsible for the fulfillment of contracts cannot afford to have it otherwise.

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DISCUSSION ON "THE CORONA VOLTMETER" (WHITEHEAD-PULLEN), CLEVELAND, OHIO, JUNE 29, 1916. (SEE PROCEEDINGS FOR JUNE, 1916.)

(Subject to final revision for the Transactions.)

L. W. Chubb: Dr. Whitehead's paper brings before us a new standard voltmeter which I think, if all the irregularities can be taken out of it, should displace the sphere gap as the primary standard. There is some doubt as to the practicability of the scheme for a working or secondary standard.

In the earlier papers Dr. Whitehead has given us an idea of the sharp indications of the appearence of corona and his Table I, in the present paper certainly is an exhibit of remarkable observations by three different methods; and we are to understand that the fourth method also checks equally well. The structure has a great advantage over the sphere gap, in that it is independent of extraneous objects. Dirt specks, oil, etc., to a certain extent, affect both types of meters but the enclosed wire is less apt to have dirt settle on it.

Several other schemes for crest voltmeters have been described in the PROCEEDINGS and I have had experience with all of them, including the Ryan type of corona voltmeter. One of the old students of Prof. Ryan set up a cone-shaped corona voltmeter in the laboratory several years ago, and tests showed that the indication of transients was its greatest advantage. When a surge in voltage would come, you could see the corona shoot toward the large diameter end of the cone. As a practical instrument, however, and for indications of steady voltage it did not seem to be a success. In all our experience, the scheme which was reported in my paper at the midwinter convention last February, we still believe is the most practical and the best for all around testing.

I would like to ask Dr. Whitehead a few questions in regard to the paper. In the first place he speaks of not having an absolute method of calibration, and points out that the value of the instrument depends upon a calibration, which can be accepted universally. At the present time the calibration depends upon an empirical formula for the electric strength of air. I believe if the method of calibration is used, that was presented in our 1913 paper, the author will obtain great satisfaction, because it is an absolute method which works from the high-tension side and depends only on a current or potential standard and the physical dimensions of a guard-ring air-condenser.

The crest-factor calculations in the paper are carried out too far. I have found that it is very hard to calculate crest factors accurately with small amplitude oscillograms, and unless a voltage measuring method is used which derives voltage from the high-tension winding and corrects for the crest factor, there may be an appreciable error.

I was surprised at the inaccuracy of the tertiary coil in the tests. It was more than is usually to be expected and the dif-

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ference between tertiary voltage and calculated voltage should have been checked by tests with parallel variable-load reactance. I would ask whether humidity has any effect on the results and whether there is any appreciable error in reading the air temperature inside of the tube It seems to me that the adiabatic expansion and compression, due to rapid change in pressure, will cause temperature changes which cannot be followed by a sluggish thermometer. I would suggest that a test be made to measure the same voltage, first by holding the voltage constant and letting out the air, then by holding the pressure constant and raising the voltage.

I would ask whether improper centering and vibration of the wire will affect the calibration, and whether the author would expect two voltmeters built to the same specifications with the usual workshop precision, to check accurately

Clayton H. Sharp: It seems clear to me that Dr. Whitehead has given us a splendid instrument, which, although the exact value of the constant may not be known, is superior to anything we have now for the purpose of standardizing high-voltage measurements. It may not make an everyday working instrument, perhaps for the same reason that the Siemens electrodynamometer is not a good working instrument; that is, that it requires an extra manipulation to give a reading, namely an adjustment of the pressure of the air. Hence it is not so quick as a direct-reading instrument might be, but as a standard instrument it seems to leave little to be desired, when once the correct value of the constant in the equation has been determined.

James R. Craighead: We should give Dr. Whitehead credit for the procedure he pursued in the development of this instrument. It was, in the first place, simply an instrument used in air, and without special standardization of conditions other than the exact dimensions of the physical apparatus. In its present form, it shows a degree of accuracy which should be amply satisfactory for its use as a standard, and the reason for that accuracy is the fact that the conditions have been so carefully controlled.

One further point—as soon as you inclose a high-voltage conductor and have corona develop, there is an ionization of the air, which is used as an indication of the actual development of corona. On some instruments of a somewhat similar character, I have observed that a certain amount of that ionization remains for a considerable period of time in the enclosed air, and I should like to ask Dr. Whitehead whether he has any difficulty in repeating immediately and frequently successive observations within this enclosed chamber without any device for ventilating in order to produce air that is free from ionization.

The point that Mr. Chubb mentioned in regard to the change of temperature that is associated with change of pressure, seems to me to be especially important. If we are to measure a voltage by the use of an air pressure, we are going to pump air at a de-

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finite temperature into a cylinder, and then a change of temperature will be going on within the cylinder to some extent as the pressure diminishes, and an accurate record of the temperature at the moment when the corona appears might be diffcult to obtain.

C. Francis Harding: The paper presented by Dr. Whitehead marks another signal advance toward the much desired primary standard for high-voltage measurement to supersede the needle and sphere spark gaps.

In analyzing this problem of the measurement of high voltages care should be exercised not to confuse methods suitable for fairly accurate practical measurements, with the requirements of a primary standard of voltage. A primary standard, if I understand the term aright, should be based upon fundamental laws a knowledge of which, together with the constants of design of the apparatus will enable such a primary standard voltage to be reproduced under any local conditions which may exist. This is not possible with the needle spark gap and there is probably some error in the hypothesis and therefore in the values of calculated voltages for the sphere gap. Several investigators have pointed out the rather large errors possible, due to varying local conditions such as foreign matter upon the spheres, distorted electrostatic field between spheres, effects of varying air pressure, temperature, humidity, frequency, etc. Furthermore the present dual standard of needle and sphere gaps for use below and above 50 kv. respectively is particularly objectionable since the two standards can not readily be made to coincide at the transition point where both should be correct. Such a method gives only an instantaneous indication of the voltage and the measurement itself, by means of the spark-over, is quite likely to disturb the circuit to such an extent as to prevent the maintenance of the desired voltage in the circuit not to mention the impossibility of a permanent indication of the same. Both spark-over methods, although valuable for practical tests are unsuited for use as permanent primary standards.

The application of a definite ratio of transformation either from a constant-potential transformer or from a voltmeter coil of a high-voltage transformer to the present primary standard of voltage has apparently been used for practical measurements with considerable accuracy. I do not see that one can ever hope to use it however as a high-voltage standard, since it is dependent upon the condition that this coil inclose the average flux of the secondary coils under all conditions of load and power factor. While this condition may be closely approximated by carefully locating the voltmeter coil, one would not feel safe in predetermining such a ratio from design data. There is no way to prove that such a calculation is accurate save by the spark gaps, and the latter have been in turn based upon the ratio method in the first place. In the paper under discussion considerable error has been reported for one particular placing of

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the coil. The speaker has found it necessary, in the determination of corona losses upon transmission lines, where the voltmeter coil was used as a convenient intermediate agent, to plot calibration curves between standard volts determined by the present sphere-gap standard, and voltmeter coil readings for each change of secondary connections. For example, the addition of 800 feet of No. 4 B & S transmission line with a 12-foot spacing will offer sufficient capacity at 180 kv. to cause the actual ratio curve to depart 8 per cent from the straight line calculated from the constant ratio which is accurate at lower voltages. In this transformer the voltmeter coil is made up in two parts, each of diameter of the average secondary coil and so placed as to inclose as nearly as can be predetermined the average flux of the secondary. This error is about the same as that reported by Dr. Whitehead for the voltage coil method with the capacity of the 100-kv. corona voltmeter in circuit.

In looking further for possible primary voltage standards it would seem logical to investigate the possibilities of making use of the force action in a uniform electrostatic field just as our low-voltage instruments make use of uniform electromagnetic fields. The former are quite as readily produced at high voltage as are the latter at low voltages.

In a written discussion of the paper on "Crest Voltmeters", the speaker outlined briefly some work by Messrs. Phelps, Wright and Holman carried on during the last two years at Purdue University upon the use of force action between parallel plates at high voltages, in which the theoretical calculated constant ratio between voltage and distance between plates for a constant force action was very closely checked in actual tests. This apparatus, constructed upon the principle of the Kelvin attracted disc electrometer, may have some possibilities as a primary standard for high voltages, although not suitable for use in a portable secondary voltmeter.

Another investigator, Mr. L. L. Bouton, also of Purdue University, has this year shown conclusively that there is little of value to be expected from an instrument based upon the attraction between metal spheres of large size, for, although test values can be reproduced more readily and are probably less influenced by local conditions than the spark gap, yet accurate theoretical determination of the field and the resulting force action between spheres is very difficult when the diameters of the spheres are large with respect to the distance between their centers.

The paper under discussion presents another apparently very fertile field for the study of possible high-voltage standards. Although many factors are involved which should and probably can be readily held constant in such an instrument, this apparatus has the advantage of several check readings for determining the critical voltage. It would seem also that if the dielectric strength of air under specified conditions were standardized,

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that this method of determining voltages would be entirely reproducible.

I wish to emphasize as forcibly as I may the importance of the early study of this problem of high-voltage standards by the proper committee of the Institute. The use of high voltages has become so general that we must have something more definite to use as a reference, a standard which may be reproduced at any time with any local conditions, guaranteeing a test voltage determined by the use of proper constants calculated from the dimensions of the apparatus involved and the fundamental laws of the electric and magnetic circuits.

F. W. Peek, Jr.: I have heard a great many arguments for and against the various methods of measuring high voltages. It is generally a question of which method is most convenient and most adaptable to any given investigation. All of the methods discussed have their advantages and disadvantages. In investigating high voltages of extremely short duration, durations in the order of a millionth of a second, I have found the sphere gap necessary. When the sphere gap is properly used, it is not difficult to use it in that way, it will measure correctly a-c. voltages, d-c. voltages, and transient or lightning voltages. I will not say more about the measurement of transient voltages here, but will refer you to my paper read in San Francisco, September 1915. This paper also gives the characteristics of transient corona produced by voltages lasting only one-millionth of a second; it is possible to see this corona and to detect whether the wire is positive or negative.

Jacob Kunz: It is possible to add still another instrument to measure d-c. or a-c. voltages. Dr. Whitehead has used the electroscope, the galvanometer, and the telephone. It is possible still to add to those corona-measuring devices an instrument which directly indicates pressure, because as soon as the corona starts, either d-c. or a-c. corona, the pressure increases noticeably and measureably. It is very easy in the case of air with voltages only as high as 10,000 volts to get an instantaneous increase of the pressure to say 3 cm. of mercury. This new voltmeter, which is based on the increase of the pressure due to the corona itself, is very accurate, and we have found recently you can use this increase of pressure by means of an aneroid barometer to measure voltage or current; the positive corona current, at least being proportional to the increase of the pressure, so that by an aneroid barometer, one can also measure currents and potential differences.

This brings out a precaution which has been taken in this instrument of Dr. Whitehead's, namely, that it uses change of pressure in order to find the starting point of the corona, but when the corona starts, then the corona itself changes its pressure. There is a reaction of the pressure, as the corona increases the pressure itself increases, and if you keep the corona going, in a little while heat will be developed, which has to be taken into account also.

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Concerning the constants of the formulas—we have thirty-two in the formula of Whitehead, and a different constant in the formula of Peek.

I think a careful investigation should be made into these constants, because Farwell found that these characteristic constants in the corona are distinctly different for positive and negative corona.

Then it has just been mentioned, that the a-c. corona for high frequency is different from the a-c. corona for low frequency, or d-c. corona; indeed, you can make experiments, and if you use d-c. corona and introduce only a little spark-gap of a mm., or half a mm., then the visual phenomenon of the corona is entirely changed and the characteristics also are very much changed. So far as I understand Townsend and Watson, they always used spark gaps in connection with the corona, and through these spark gaps the nature of the visual corona is entirely changed; for instance, in a d-c. corona with the spark gap, the positive wire is surrounded by a uniform glow and the rest of the tube is dark. If a spark gap is introduced, however, the whole corona is filled with streams of light, which are separated from each other, and in some cases they are very uniform and the whole tube glows uniformly.

Corona assumes quite a different character, for instance, in the case of hydrogen. Experiments have been made in our laboratory on corona in hydrogen and other gases, and the characteristics between positive and negative corona are entirely different. They do not resemble each other—one is a continuous and the other is a discontinuous corona, and the negative corona appears in the form of beads, while the positive corona is uniform. In this case, the difference between positive and negative corona in hydrogen, is so great that the hydrogen corona tube can be used as a rectifier. We have been able to rectify voltages up to 10,000, and there is no reason why we should not be able to rectify 100,000 volts.

John B. Taylor: Can the method of determining corona formation by listening for sound in a telephone receiver be used when working with continuous voltage?

F. W. Peek Jr.: Some years ago we rectified by corona in air. A full description of this is given in an Institute discussion.

J. B. Whitehead: I think all of the speakers have agreed that our instrument has some promise as a standard. That was our chief object. Our feeling is also quite pronounced that it will also be a working standard, but we are quite satisfied at this time to find such a unanimity of feeling that there is here the possibility, at least, of an ultimate standard of high voltage.

As to the cone shaped wire mentioned first by Mr. Chubb and last by Dr. Lloyd. The cone shaped wire, in giving the direct scale, has this one difficulty—that the presence of corona causes a slight elevation of temperature. This slight elevation of temperature means that corona will appear at a lower voltage, so,

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consequently, if you use the cone shaped wire, even supposing you hit the actual voltage immediately by seeing the point along the length of the wire at which it comes out, that position will change almost at once. Corona on a vertical wire, is often seen to walk up the wire, owing to this cause, hence the difficulty of securing anything like permanence in the graded diameter.

As to the determination of peak factors, the general conditions under which our oscillograms were taken are described in the paper. A third decimal place has slipped in, as a result of taking an average of several values. I agree with Mr. Chubb that it is not possible to measure peak factors to the third decimal place. However, the gradual variation of the peak factor as described in the paper was quite obvious in our determinations, taken over a wide range. The comment is quite proper. The weakest point in the determination of maximum value readings of voltage from the low-tension side, is the oscillogram.

The transformer which we used was constructed before the engineers who are interested in the possibilities of the tertiary coil were quite as certain as to the accuracy attainable, as they are now. Having consulted them, they agree that the design of the transformer that we have, as regards the tertiary coil, could be greatly improved. My comments on that point are not intended in any sense to depreciate the present day value of the tertiary coil, as a means of measurement.

As regards the humidity inside of the tube, if you allow the air in a corona tube to expand very rapidly through an orifice, you will undoubtedly get cooling as you will everywhere in the rapid expansion of air, and you will also have condensation of moisture. In our experiments, this matter is readily taken care of by providing a large opening for the air and letting it out so slowly that you do not get appreciable cooling and condensation. By providing large enough openings, the air can be changed very readily, and you can get as uniform a distribution of temperature as you please. The temperature is measured with a thermometer inside. So far as we have been able to observe we have not found any indications that this is a serious difficulty—indeed, we have not observed it as a difficulty at all, we have never found anything other than a slow change of one or two degrees throughout the course of a full run.

The centering of the wire is purely a mechanical process. We have suitable templates for the inner tube of the voltmeter, as shown in the diagram, and these templates can be adjusted through the side hole which is large enough to get your hand in, and by looking into the side hole at right angles and shifting the template, it is easy to determine the centering. The final centering is done in the instruments we described at the ends. The holes through the insulators are large enough to give us quite three or four mm. in any direction, and this is found to meet the situation.

Mr. Craighead raises the question about ionization. Some

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of my earlier experiments convinced me at least, although not every one, that the normal ionization in the air has no effect on the beginning of corona. These experiments included the location of radio-active substances in the neighborhood, illuminating the wire for ultra-violet light, and other well known sources of ionization, so that there was no lowering of corona voltage.

On opening the corona voltmeter after prolonged use, there is very decided evidence of ozone. We have never been able to detect, however, any variation from the calculated values of corona.

With reference to Prof. Kunz's very interesting description of the use of the elevation of pressure as corona detector I hope he will present the results of his studies in that direction so that we may have a complete account of them. I would like to call attention, however, to the fact that in the use of the corona voltmeter by which we read pressures to one-quarter of an mm.,—of course, we could read them more closely, but that is quite sufficient to give an accuracy of less than one-half per cent—we have never detected any increase in pressure due to the presence of corona. That does not mean Prof. Kunz has not found the increase of pressure, but we are working on the threshold appearance of corona where the increase of pressure is very small. It is very small because we have quite a large volume of air in the corona voltmeter, and it is only the initial appearance of corona; consequently there is a generation of but very few ions, considered with reference to the number of molecules in the whole volume of the system. The use of elevation of pressure as the result of corona would seem to me to be subject to this very limitation that he speaks of in the resulting temperature. Certainly we have found that if we carry the voltage above the corona-forming voltage, five or ten per cent above, so as to get a large corona, changes in temperature are immediately obvious, and consequently they would introduce error.

Prof. Kunz, I am sure, will be interested to hear that we have carried out some d-c. experiments during the past year, in which we have been able to get negative corona without the appearance of beads, and I believe that the negative corona without the appearance of the beads and localized spots is simply a question of constancy of circuit conditions and of clean surface. That is our conclusion. If you allow negative corona to remain any time, after awhile it will form into these beads, but there is no doubt that negative corona can be obtained without the localized sparks.

As to Mr. Taylor's question—the sound given out by the corona is not the note corresponding to the frequency of the circuit, it is entirely due, in my opinion, to indiscriminate snapping sparks over the minute irregularities of the surface of the wire, irregularities which cannot be gotten rid of, although we polish it to a very high degree. Therefore, although we have not before

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us, the account of our experiments on the sound of d-c. corona, I feel sure that the sound could be used there also.

Since the experiments reported in the paper, we have compared the corona voltmeter with the sphere-gap, as shown by Fig. 1. The upper solid curve is the calculated corona curve, using the formula of my work, namely 32, for the first constant, or 0.518 for the second. The long dash upper line is the curve of corona voltage as taken from Mr. Peek's formula, namely, 31 for the first, and the second constant is 0.54. The curves are plotted between kilovolts per centimeter at the surface of the wire, and the range of atmospheric change, affecting the whole range of the abscissa, is 10 or 15 cm. below atmosphere, to 45 or 50 cm. above atmosphere, so that this is a rather wide range of air

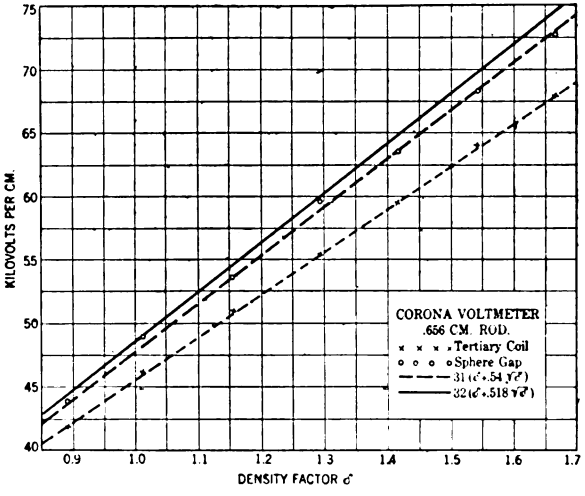

FIG. 1

density, and therefore the difference between Mr. Peek's constant and my own appears somewhat intensified.

Now, then, the lowest curve with the cross marks gives the observations on the tertiary coil of the transformer,

The tables shown in the paper give the accuracy with which the low-tension reading can be repeated, and the circles with the dots represent the sphere gap readings, all these measurements being taken on a 12.5-cm. sphere-gap. The readings were taken as follows: We would set the pressure and gradually raise the voltage until corona appeared with the spark gap in parallel with the corona tube, set to a value which we knew was too great for spark-over. Keeping the pressure in the tube constant we would repeat over and over again the corona observation, closing the sphere gap by 1/100 mm. each time. Finally

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we came to a voltage value in which the sphere gap would let go just before we had the corona.

The interesting point about the curve, it seems to me, is that it shows that the calibration of the spark gap and Mr. Peek's corona values, are of course, coincident because they are based on the same standards and methods of measurement. The falling of the tertiary coil observations below these is entirely due to the construction of the tertiary coil. The variation of the spark-gap determination from the calculated curve would not ordinarily be considered great. I call attention to the irregularities of the gap readings as compared with those of the corona, as referred to their respective curves.

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DISCUSSION ON "SUBMARINE CABLE RAPID TELEGRAPHY; OCEAN AND INTERCONTINENTAL TELEPHONY". (BELA GATI), SAN FRANCISCO, CAL., SEPT. 17, 1915. (SEE PROCEEDINGS FOR SEPTEMBER, 1915.)

(Subject to final revision for the Transactions.)

Otto B. Blackwell (communicated after adjournment): Without attempting a complete criticism of Mr. Gati's paper, I wish to comment on certain statements made in it, particularly those regarding telephony.

"Only the shunted coil cable is suitable for ocean telephony its resistance being only 24,680 ohms at 4000 kilometers. The length of the South American and African connecting cable is less than 4000 kilometers, and so, on these cables ocean telephony is already possible; naturally only with the aid of the one frequency system."

This interesting conclusion is drawn from Table IV. Let us consider the assumptions on which this table is based. We find first, that the leakage is taken at one micromho and the capacity at 0.23 microfarad per kilometer. This gives a ratio $g/c = 4.35$. For a frequency of 1600 cycles, for which the table is computed, this is considerably better than would be realized in the best standard types of telephone cable insulated with a loose wrapping of very dry paper. I have seen no figures given on dielectrics for submarine use which approach this figure. It is moreover, inconsistent with the value assumed for comparison in computing Table III for Krarup cable.

We find next that the shunt coils are assumed to have per kilometer an inductance of 0.04348 henry with a resistance of 0.0189 ohm. This gives a ratio of $R/L = 0.435$. A coil having a ratio of $R/L = 45$ at 1600 cycles is considered a good coil for land lines. While the shunt coils could economically be much more expensive than the coils for land lines in view of the value of the cable and the infrequent spacing, they would be subject to severe mechanical limitations as they would need to be suitable for deep sea use. We must, therefore, consider the coil efficiency assumed as entirely unreasonable.

Considering next the formula used, it should be noted that equation (8) does not take account of the loss in the loading coils. For a reasonable assumption as to coil efficiency, this becomes very important.

To indicate the effect that these changes in assumptions and formula would have, I have had computed the attenuation constant and "total resistance of cable in ohms" for 4000 kilometers assuming the cable to have the same capacity and resistance as used in computing Table IV but assuming a ratio of $g/c = 14.5$ which is that assumed by Mr. Gati for the Krarup cable (this however being better than realized in practise), and a ratio of R/L of 45. On this basis $\beta = 0.0035 + j\,0.0039$ and the "total resistance of cable" for 4000 kilometers is 154,000,000. This latter figure is to be compared to the value of 24,680 computed in Table IV for the same distance.

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Assuming, however, for argument that it were possible to realize a cable having at the assumed frequency the constants stated in the paper, there is still the difficulty that the frequency assumed is only about 1600 cycles. As noted in the paper, the carrier frequencies suggested for this purpose by Squier and others are very much higher than this value and would be subject to very much larger dielectric and coil losses and, therefore to very much larger attenuations.

In addition, but apart from the above, there still remains a controlling reason why a shunt loaded cable of this type would not be effective for long distance telephony. The paper states the cable would be used "naturally only with the aid of the one frequency system." A carrier current modulated in amplitude in accordance with the variations in a telephone current, is however, not a single frequency system at all. It involves a satisfactory transmission of a range of frequencies, of the same order of magnitude as is involved in the ordinary telephone transmission, *i. e.*, about 2000 cycles or more. We must, therefore, either for carrier currents or without them consider the attenuation of the cable not at one frequency but at a range of frequencies. It is exactly in connection with this matter of a range of frequencies that shunt loading is inefficient. For example, taking the assumptions of the paper for the shunt loaded cable as used in computing Table IV. we find at 1600 cycles an attenuation constant of about 0.0011 and at one-half this frequency or 800 cycles an attenuation constant of about 0.05; that is, the attenuation at 800 cycles is over 40 times as large as at 1600 cycles.

We must conclude, therefore, that South America and Africa are still considerably farther apart telephonically as far as cable circuits are concerned than Mr. Gati's computations led him to believe.

The above discussion, except for the last factor mentioned (frequency range) applies also, of course, to the conclusions drawn as to the use of the shunt loading for ocean telegraphy.

Without entering into a detailed discussion of the characteristics of shunt versus series loading, the following facts will give a general idea of their relative characteristics.

1. For currents of a given *single* frequency, the reduction in transmission losses which can be obtained by loading a circuit with coils of a given efficiency is the same, whether the loading be series loading, shunt loading, or a combination of the two. The efficiency of a coil for this purpose is measured by the ratio of its effective inductance to its effective resistance.

2. For telephony, series loading has a controlling advantage over shunt loading, in that it provides a circuit having transmission losses which are approximately the same over a wide range of frequencies. This range of frequencies can readily be made broad enough to include all frequencies important in telephone transmission. The effect of shunt loading varies greatly with the frequency, making it undesirable for telephone use.

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3. For single frequency currents, shunt loading has the advantage, under some conditions, of permitting a greater distance between loading coils than with series loading. For this reason it might be preferable in cases in which it was desired to transmit a single frequency only.

In the last part of his paper, the author discusses the question of increasing the range of telephone transmission on land. In this connection, it should be appreciated that the commercial application of any particular means for increasing the range of telephone transmission involves a great many difficulties to be overcome, aside from those involved in the particular means itself. These difficulties arise from the complicated nature of the service given by a commercial telephone system. For example, an increase in the output of the transmitter or in the efficiency of the receiver increases the magnitude of the interference effects between different telephone circuits which, from the nature of the telephone system, must be in very close physical relation to each other. Because of the high frequency of the telephone currents, the tendency for such inductive effects between the telephone circuits is large. In addition, an increase in the efficiency of receiving apparatus tends to increase the volume of sound produced by the inductive effects of power circuits and other sources of inductive effects to which the telephone circuits are exposed. Moreover, changes which affect the telephone toll lines can be made only after a consideration of their effect on the superposition of the telephone and telegraph circuits on the same wires, necessary in order to obtain an economical use of the conductors. These remarks are made to emphasize the fact that extending the range of telephone service, or any other improvement of telephone service on a commercial system, cannot be brought about by a single change in circuits or apparatus, but necessitates the application of many modifications in different elements of the system and the consideration of the ways in which these changes react upon each other and upon the system as a whole.

In his discussion of means for increasing the range of transmission over land, the author brings forward the proposition of using single-wire circuits with ground return, pointing out, however, certain disadvantages. Under the conditions in this country, single-wire circuits cannot, of course, be seriously considered for toll lines, considering the large number of power circuits and other sources of induction to which the telephone lines are exposed and considering the large number of telephone circuits which must be run on a single lead. In this connection, however, the paper appears to make the mistake of supposing that with a single line and ground return the leakage will be less since "the 50 per cent. of the leakance places and leakages are avoided." It is evident, however, that the single wire with ground return has more leakage than a two-wire circuit since in the two-wire, at any crossarm, the leakages of the two insulators are in series, not in parallel, as far as the telephone circuit is concerned.

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I note a number of mistakes in computation in the tables. With the assumption made in the paper for a Krarup cable we obtain a value of $Z_0 = 109\ /\overline{0°55'}$ instead of the value given. This reduces all the values in Table III by about a factor 3. It is not evident for what conditions the assumptions as to l and c in Table VI are made; they appear to vary inconsistently with size of wire. Also, the angle of Z_0 for the 5- ohm wire and the real component of α for the 1.7-ohm wire appear to be in error.

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DISCUSSION ON "CREST VOLTMETERS" (SHARP AND DOYLE), "THE CREST VOLTMETER" (CHUBB), "THE VOLTMETER COIL IN TESTING TRANSFORMERS" (HENDRICKS), "NOTES ON THE MEASUREMENT OF HIGH VOLTAGE" (WORK), NEW YORK, FEB. 8, 1916. (SEE PROCEEDINGS FOR FEBRUARY 1916.)

(Subject to final revision for the Transactions.)

E. E. F. Creighton: The question of the measurement of high frequency is always important, and always will be important until all the problems relative to the protection of apparatus are solved. Dr. Sharp's statement that the kenotron might be used for the measurement of high frequency is of the greatest importance. The dielectric spark lag of a perfect vacuum is practically infinite, because there are no ions present. Going down to a vacuum of something like fifteen millimeters in the usual gases the dielectric spark lag decreases to about the low value at atmospheric pressure.

It would be of interest to know in these cases how high frequencies were used in the kenotron. I had a feeling that there was not sufficient ionization in the tube to reduce the dielectric spark lag to a value which might give direct indication of the voltage. If the dielectric spark lag is not great, or if it can be taken care of at high enough ionization with the filament, there should result another instrument for measuring transitory waves in transmission lines. These waves are very difficult to get at.

At the present time we have to depend upon a number of sphere gaps connected in parallel, each one set to a different voltage. For example, in the measurement of a 13,000-volt circuit we naturally begin with the sphere gap set on double potential and go on from that to 2.5, 3, 3.5, 4, etc. In series with each one of these sphere gaps is placed a recording device, usually operating on the principle of the Branly coherer. If, however, the kenotron can be used for these high frequencies, high potentials, it will give a simpler method of measuring and recording these transitory voltages.

F. W. Peek, Jr.: I have used one or the other of these methods in measuring high voltages at the ordinary frequencies of power transmission, high-voltage direct current, transient voltages of the duration, in some cases, of a few millionths of a second, and continuous high-frequency voltages. The voltage range in these measurements was from zero to almost a million volts. I shall review the various methods and state their possibilities and limitations as I have found them in my experience.

For the purpose of discussion, the methods of measuring high voltages may be divided into three classes, (1) the spark gap; (2) the crest voltmeter consisting of a condenser and a rectifier in combination with frequency meters, ammeters, or static voltmeters connected directly to the high-voltage line; (3) the voltmeter coil, on the high-voltage side of the transformer, in combination with a low-voltage crest voltmeter.

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In discussing (1), the spark gap, it is only necessary to consider the sphere. With this form of gap there is no humidity correction to make. The correction for air density is readily made. The sphere gap will measure correctly the crest voltage of the most distorted wave; it will measure correctly, direct current, high frequency over a considerable range, and impulse and transient voltages of a few micro-seconds duration.[1] In many high-voltage measurements the sphere gap is very desirable, in fact, necessary, to detect oscillations. It is invaluable in the laboratory in investigating transient voltages. The disadvantage of the sphere gap is that it must be set.

Under (2), two forms of crest voltmeters connected directly to the line have been described. In the method described by Mr. Chubb unidirectional voltage is applied to a condenser by means of a rectifier. The current and frequency are read. Good results may be obtained if the wave shape is not much distorted. Errors will result if there is insulation or corona loss in the condenser as this loss current will be read on the meter. If the voltage wave has a double peak, or a sharp peak, large errors will result. This is shown in the paper by Mr. Work where a wave of the type Fig. 14 causes an error of over 40 per cent. This is a much larger error than would have resulted if no attempt had been made at correction. In the method described by Messrs. Sharp and Doyle the rectified voltage wave is applied to a condenser. The condenser is thus charged up to the maximum of the wave. The condenser voltage is read by a static voltmeter. I have used this method directly on the line for voltages of over 100 kv. I believe it to be the more practicable of these two methods. Good results may be obtained if the insulation is very good and the condenser is of fairly high capacity. If leakage occurs the voltage reading will be too low. Thus, for high voltages, the condensers become excessively large. More will be said of the application of this method at low voltages, later. Both of these methods have extensive use in the laboratory and may be of use in some practical work. Neither will measure transients or detect oscillations.

The voltmeter coil, method (3), consists of taps brought out from a few turns of the high-voltage winding of the transformer, generally at the neutral point where the voltage above ground is zero. I have for years used a transformer, designed by Mr. Hendricks, equipped with such a coil. I have made hundreds of check tests with voltmeter coils and find that when the transformer is properly designed, and the coil properly placed, the voltage and the wave measured from the coil check very closely with the voltage and wave shape across the high-side winding. The voltmeter coil requires practically no extra equipment and involves practically no extra cost. The effective voltage may be read by a standard voltmeter, the maximum may be read by a

1. F. W. Peek, Jr., "The Effect of Transient Voltages on Dielectrics." A. I. E. E., August, 1915.

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low-voltage crest voltmeter. This crest voltmeter may be of the type described by Messrs. Sharp and Doyle and need not be large and expensive as in the case of the high-voltage types. An oscillogram of the voltage wave may be taken at any time. The voltmeter coil with crest voltmeter seems to be decidedly the best and most convenient method of measuring high voltages in practical testing where continuous readings are desired. This should always be supplemented by a sphere gap set slightly above the applied voltage to detect oscillations, etc.

The methods of measuring high voltages may be summarized as follows:

(1) The sphere gap will measure correctly practically any form of voltage. It is the only method, at present, of measuring certain high-frequency and transient voltages. It is invaluable in the laboratory and in much commercial work, especially where transients are likely to occur.

Its disadvantage is that it does not read continuously. This is not always a disadvantage as the transformer may be calibrated.

(2) The various crest voltmeters consisting of condensers, rectifiers, voltmeters, ammeters, and frequency meters, connected directly to the high side of the line are useful over a limited range in practical work, but become troublesome, liable to error, and expensive at high voltage. They are not always accurate with distorted waves.

(3) The voltmeter coil in connection with a low-voltage crest voltmeter involves practically no extra space or expense and gives good results. The voltmeter coil with crest voltmeter and supplemented by a sphere gap to detect oscillations offers the best arrangement for general commercial testing.

F. M. Farmer: The problem of measuring high voltages usually involves two things, the mean effective value and the maximum value.

The first method used for measuring high voltages employs the low-tension voltage and the ratio of transformation. This method is deficient, in that we do not know anything about the ratio under varying load conditions nor have we any knowledge of the crest factor.

The next scheme developed was the use of electrostatic voltmeters on the high-voltage circuit. That gets rid of the ratio difficulties and gives us a mean effective value, but the scheme has voltage limitations because of construction difficulties at very high voltage and also because stray electrostatic field troubles become serious. Furthermore it does not give the crest voltage.

The test coil seems to be the proper thing for measuring mean effective values on the high-voltage side, but there again, some investigation is necessary to be sure of the ratio of the test-coil voltage to the total voltage under various load conditions and various dispositions of the sections of the secondary winding. Of course, in our very high-voltage testing, it is not customary to

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divide the high-tension winding, but in the ordinary testing transformer for routine testing at moderate voltages, the secondary winding is split up into two, four, or even eight sections, so as to be able to get the maximum kilovolt-ampere capacity of the transformer at all voltages.

The best arrangement, therefore, seems to be the use of a test coil in the high-tension winding of the transformer. An ordinary voltmeter gives the mean effective value and a crest voltmeter gives us the maximum value.

There is one question I would like to ask Mr. Chubb. Is there any variation in the capacitance of the condenser bushing? At the very high voltages is it possible that that capacity will change and thus introduce an error. In other words, does the capacity remain constant at all voltages?

Frederick Bedell: One feature of the crest voltmeters described in these papers is that it is possible by means of them to obtain an instrument reading of crest voltage without the use of a synchronous contactor. Another method for obtaining such readings without the use of any synchronous device is the method described[2] by Professor Ryan in which an impulse transformer is employed, in place of a synchronous contactor, in conjunction with the Duncan method for obtaining a-c. wave form. The impulse-transformer method makes unnecessary the synchronous contactor, but it does require the locating of the maximum reading by trial, so that readings of crest voltage are not made directly as by the crest voltmeters we have just heard described.

Comfort A. Adams: I agree thoroughly with Mr. Hendricks that it is unnecessary to go to great lengths in the measurement of peak voltage, provided you have a suitable alternator and transformer and can depend upon the voltage wave shape impressed upon the transformer, in which case an ordinary voltmeter connected to a suitably placed voltmeter coil in the transformer, will give very fairly accurate results. Moreover, such an equipment is desirable not only because it facilitates voltage measurement, but also because harmonics in the e. m. f. wave are undesirable on at least two other accounts. They produce undue heating of the dielectric in some cases, and also tend to encourage transients of still higher frequencies.

We have much to learn on this subject of insulation and cable testing. In high-voltage testing very high-frequency transients of excess voltage do occur, of this there is ample evidence, and until they are under control or brought within the realm of measurement, it behooves us to go slowly. As yet the spark gap in some form is the only simple detector of transients, but even if it could be conveniently arranged for measurement rather than for detection, it would still be dangerous because of its habit of producing the very kind of a disturbance it is employed to detect. Some materials withstand abnormal transients without rupture, provided they are not repeated too often, while

2. TRANSACTIONS, Vol. XVI, p. 345, 1899.

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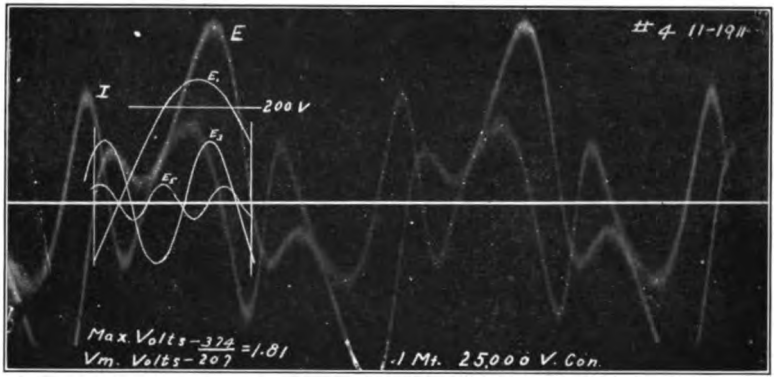

FIG. 1 [MIDDLETON]

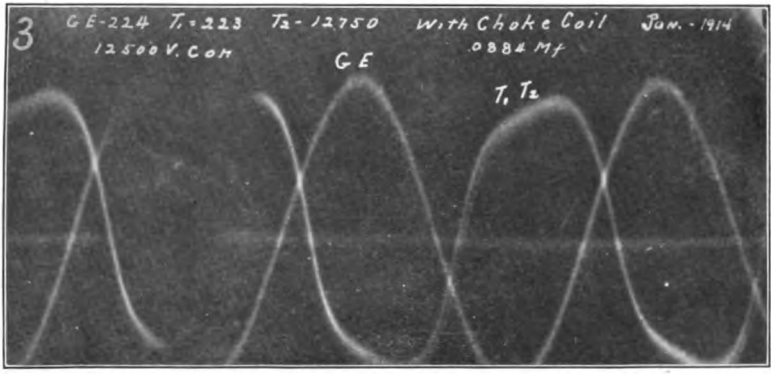

FIG. 2 [MIDDLETON]

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more fluid materials will fail and heal up many times before final rupture.

W. I. Middleton: It is very apparent from the papers that have been presented here today that the importance of a knowledge of the maximum voltage in connection with high-voltage testing is being appreciated more and more. It is not so much a question of whether the wave is distorted or not, but as to how much, and until generators giving a sine wave under a testing load are more commonly used than at present, it should be the desire of all interested to develop an instrument or instruments, that will give a direct reading in volts of the pressure at the peak, or crest, of the voltage wave.

In the early part of 1900 all of our investigations in high-voltage testing were done with the spark gap, and by its constant use under every condition of test that would arise, we were convinced that it was impossible to tell accurately what was the maximum voltage being applied to a cable under test.

In the latter part of 1911, while investigating the variations in the voltage waves of our testing set with an oscillograph, Mr. Dawes and I decided that as it was the peak of the wave we were interested in rather than its shape, an instrument much simpler than the oscillograph could be made, and in April, 1912, a working model of our instrument was being used in our factory.

The authors show some badly distorted waves obtained under testing conditions: We have experienced considerable difficulty from just such waves.

Fig. 1 shows a voltage wave obtained from a single-phase generator when it was supplying power to a step-up transformer, to the secondary of which was connected a cable undergoing test. The voltage wave is not unlike some of those shown in the papers. The current wave crosses the zero axis three times in a half cycle; ts third harmonic has a greater amplitude than its fundamental. We have found the peak voltmeter very useful in checking such waves.

The instrument which we are using is based on the oscillograph principle, and therefore takes a very appreciable current, so we cannot use a condenser train as a multiplier without going to considerable trouble and expense. Therefore, we are obliged to use an instrument transformer to step down the voltage.

There has been raised some question regarding wave distortion taking place through a potential transformer. We have checked peak factors at various times with our peak voltmeter, but have never been able to detect any difference between those on the primary of the step-up transformer and those at the secondary of the potential transformer. As further, evidence, we have taken oscillograms of such waves.

In Fig. 2, the wave marked *G E* is the voltage wave of a special sine-wave alternator. As we have never been able to apply a load that would produce any appreciable change in the shape of this wave, we introduced an air-core choke-coil into the line in

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series with the primary of the step-up transformer. Due to the non-sinusoidal drop through this choke-coil, the voltage at the transformer terminals had the form shown by the Wave T_1. The wave T_2 was taken simultaneously on the secondary of the potential transformer. The oscillograph vibrators were connected so that both waves were on the same side of the zero axis, and the multipliers were so adjusted that each voltage wave had the same amplitude. It will be seen that there is no appreciable difference in the shape of the two waves. There is, of course, a slight shifting of phase through the two transformers. Any variation of the voltage wave form is due to the fact that the current produces IR and IX drops in the transformer windings, which differ considerably in wave form from that of the applied potential wave. Also these waves were taken at only 13,000 volts. I realize that, at the higher voltages, distortion may occur due to capacity effects in the transformer windings.

If Dr. Sharp has developed an instrument that will trap and hold transient voltage peaks so that their value may be determined, I am sure that it will be found very useful in connection with high-voltage testing, especially in cable testing, where there is a large amount of capacity in the circuit. We have evidence that surges occur very frequently when the cable is long and the voltage is high. I am certain that many cables have punctured at voltages much higher than have been shown on the indicating instruments, due to surges occurring in the circuit. The presence of these transient peaks may be wholly unknown to the person making the test, unless he has some such instrument as Dr. Sharp describes.

J. R. Craighead: I made a few experiments and got some data in connection with the use of the kenotron with the electrostatic voltmeter on high-tension circuits at 60-cycles. In order to get the matter down to a point where a comparison could be made with the oscillograph with series resistance, voltages were used, not of the order being talked about this afternoon, but with the maximum limited to 7000 volts. The oscillograph was used photographically each time, and measurements made as carefully as possible in order to determine the correspondence between the electrostatic and the oscillograph. The electrostatic itself was calibrated on a sine wave after each successive trial, in order to be sure that the instrument itself did not change. Three waves were used, the crest factors varying from 1.405, which was practically a sine wave, up to 1.56. One of the three waves, the one whose crest factor was 1.56 had three peaks between each pair of zeros, although two of the peaks were very small.

The results, of which I have made a tabulation, show that the maximum difference within six successive trials taken of the three waves, between the crest voltmeter and the oscillograph, was about 0.2 of 1 per cent. The maximum difference on any trial was about 1.2 per cent, which was practically as close as a standard electrostatic voltmeter of 10,000 volts could be used

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at that point. All of the trials came within considerably less than 1.2 per cent, which represented the outside of the six.

In respect to the rectifier that was used, there is a characteristic of most rectifiers that causes them to have a rather definite voltage drop which is not altogether dependent on the current nor proportional to the current. In order to show as much of this drop as possible a kenotron was used which was capable of standing about 70,000 volts maximum, at about 10 per cent of the voltage it was expected to stand.

In respect to the capacity which was necessary in order to keep the voltmeter at a correct maximum reading, a very much smaller value than Dr. Sharp has suggested was found quite satisfactory. For the most part, these tests were made with 0.002 of a microfarad in multiple with the voltmeter itself.

The table to which I refer is as follows:

No. of test	Average crest factor	Average of maximum readings		Per cent variation of electrostatic voltmeter with Kenotron from oscillograph		
		Oscillograph through resistance	El. voltmeter with kenotron	Maximum positive	Maximum negative	Average
1-2	1.405	7186	7175	+ 0.7	− 1.0	− 0.2
3-4	1.485	7126	7185	+ 1.2	....	+ 0.8
5-6	1.56	7165	7165	+ 0.5	− 0.4	0

I ask Dr. Sharp if his tests were all made, as shown on the diagram, on ungrounded circuits or whether he used grounded circuits in any instance, and at what voltages the tests were made.

C. L. Dawes: There is still another type of crest voltmeter which has not been mentioned. We have found the oscillograph type of crest voltmeter very useful in connection with cable testing, but there are certain conditions under which it cannot be used to advantage because of the very appreciable current which it requires for its operation. This has led me to develop an electrostatic type of meter. The principle of the instrument is not original, but was suggested to Prof. A. A. Laws and myself by a paper written by E. T. Jones, appearing in the *Philosophical Magazine*[3] some time ago. However, the instrument there described was wholly unsuited for high-voltage testing, and therefore it was necessary to modify the design very materially.

Fig. 3 shows the general scheme of the voltmeter. For the sake of clearness, no attempt has been made to show the parts in their correct proportion. A phosphor-bronze filament is

[3] "A Short Period Electrometer and Its Use in Determining the Frequencies of Slow Electrical Oscillations." *Philosophical Magazine*, 1907, p. 238.

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stretched between two points of support AA, the proper tension being secured by the spring B. This filament is held to the spring by a short length of silk thread for insulating reasons. Beside and close to this filament a small silk thread C is stretched, being drawn as tightly as its tensile strength will permit. Across the filament and thread, midway between the supports A, a small mirror D is cemented.

In front of the filament and very close to it, a brass plate E is fastened. Through the center of E, there is a small hole just large enough to allow a beam of light to enter and leave. The filament and this plate are connected together to form one terminal of the instrument. The other terminal of the instrument is the small brass plate F, secured to the hard rubber barrier.

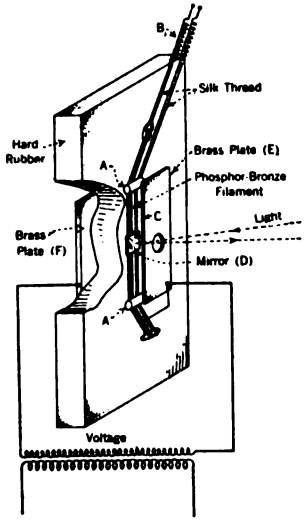
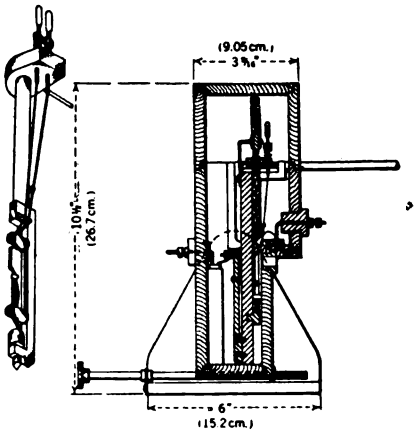


FIG. 3



FIGS. 4 AND 5

This barrier acts as a dielectric to prevent breakdown between the terminals.

When the brass plate E and the filament are both positive, there is electrostatic repulsion between them because like charges exist on both. On the other hand, there is attraction between the plate F, which now has a negative charge, and the filament. As the silk thread is not influenced by the electrostatic charges, it remains practically stationary, serving only as a hinge about which the mirror swings. Therefore, the left hand side of the mirror will be drawn toward the barrier. When the polarity is reversed, the mirror will still deflect the same way, because the charges on plate E and the filament are always the same and those on plate F and the filament are always opposite. Therefore, the mirror deflections are proportional to the square of the voltage and the deflection is always in the same direction. The

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deflection of the mirror is read by noting the breadth of a band of light upon a scale. Fig. 4 shows the vibrator which is removable from the barrier.

The instrument does not operate satisfactorily in air, due to corona and brush discharge from the filament, therefore it is necessary to immerse it in oil. Fig. 5 shows a cross-section of the instrument immersed in a box containing white oil. Connections to the plate are made through mercury cups, which connect to binding posts through hard rubber bushings.

It will be appreciated that this instrument has so little electrostatic capacity that it is almost negligible. Therefore, it is very easy to use it in connection with a condenser-train multiplier having a very small capacity. Also the instrument may be used to measure induced potentials upon insulated bodies whose capacity to the system is so small that the voltage would be disturbed by even the small capacity of other types of electrostatic instruments. For instance, Mr. Middleton and I have frequently used the instrument to measure induced charges on cable sheaths and on insulated conductors having high-potential wires in their neighborhood. This instrument does not need to be grounded, but may operate at potentials far above that of the ground. For instance, we have used it to measure a potential of 30,000 volts when one terminal was at 30,000 volts and the other at 60,000 volts above ground potential. Up to the present we have calibrated the instrument by connecting it to the secondary of a step-up transformer which is delivering no load. Under these conditions, we know the voltage wave to be essentially sinusoidal. The instrument at present can be used safely up to 30,000 volts, but there is no apparent reason why it cannot be designed to operate at much higher potentials than this, provided that appreciable corona discharge from the filament to the oil is not allowed to occur.

This voltmeter is independent of wave form and negative loops; although it cannot register surges, it has been able to indicate the apparent peak of surges in the circuit to which it was connected.

John B. Whitehead: All three of these papers describe the use of the electric valve for measuring the maximum value of voltage. Reference is made to the work of Dr. Gordon and myself in which we measured corona voltages at frequencies higher than sixty cycles. We used the mercury electric valve for obtaining maximum values of voltage at the higher frequencies, in much the same way as now described in these papers.

I mention this in order to answer Mr. Creighton's question as to the frequency at which the valves may be used. At that time we were working up to 3000 cycles. From the nature of the kenotron, I see no reason why it should not be available for far higher frequencies than this.

I wish to describe some experiments we have been making with still another type of crest voltmeter, namely, the corona voltmeter.

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It has been frequently brought to the attention of the Institute that the value of the voltage at which the corona comes out on clean wires is extremely sharply marked. Suitable corrections, which are now perfectly well understood for temperature and pressure, may be made. It is quite possible to read and re-read corona voltages on clean wires to a far higher degree of accuracy than the constancy of the usual circuit, even in a laboratory, where precautions to secure constancy are taken.

Within the last two years I have been trying to use the principle of the breaking out of corona on the peak of the voltage wave as a basis for direct observation of crest voltages. The great difficulty in using the corona, a difficulty which is at once obvious, is that it is directly dependent upon the size of the wire, and that consequently for any range of scale in such an instrument the size of the wire would have to be changed. There is another difficulty, namely, that some method of detecting the beginning of corona, other than by direct visual observation must be devised.

I have met the first difficulty very satisfactorily, so far, by enclosing the whole corona tube, with its central wire, in a larger outside tube, varying the pressure in this outer tube and, reading the pressure and the temperature in order to apply the correction. The instrument can then be set for any voltage by varying the pressure in the outer containing cylinder, or, if it is desired to measure an unknown voltage, it is simply a matter of lowering the pressure until corona appears. In other words the range of the instrument will be taken care of by running the pressure either up or down in the outer containing tube.

For the observation of the beginning or presence of corona, we have developed three very satisfactory methods. The first is that which uses the gold-leaf electroscope in connection with a small electrode outside of the cylinder forming one side of the voltage terminal, as described in my papers, the *Electric Strength of Air*. This electrode is placed directly opposite a few small holes in this cylinder and the ionization that comes from these holes is quite sufficient to discharge even a crude and rugged type of electroscope.

The second method is by the use of the galvanometer in connection with d-c. voltage. In order to use this method, the electrode is increased in size, so as to form still a third outside cylinder very close to the main cylinder forming one side of the high-voltage circuit, the latter cylinder being perforated with many holes over its whole circumference so as to provide a very large aggregate opening for ionization. With d-c. voltage on the enlarged electrode and a galvanometer in series, the beginning of corona is marked by a sudden deflection.

Still a third method which has been surprisingly satisfactory is the use of the telephone. We enclose a telephone transmitter inside of the pressure cylinder. We do not normally think of a frequency of 60 cycles as one which would give any appreciable

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note with a telephone transmitter. There is, however, something other than the normal 60-cycle note in the high voltage corona and it is these higher spark tones which the telephone seems to pick out. The beginning of corona is attended by a sharp sound in a receiver connected to the transmitter located as described. We are now using all three of these methods of observation and they show a most gratifying agreement.

We can add a fourth method, if we will, the visual corona, always a very satisfactory means of observing the maximum point, but not suitable for an instrument for use in the open, as in a manufacturing shop, or power station. The eyes must be rested in the dark at least five or ten minutes before visual corona can be observed satisfactorily.

L. W. Chubb: In the paper by Sharp and Doyle the authors speak of leakage demanding a certain amount of capacitance in parallel to the meter. The dielectric resistance of electrostatic voltmeters is usually very much higher than any condenser, unless it be of the air type. Also, the rectifier resistance is higher in the reverse direction than that of the condenser, so that if more condensance is put in parallel we should expect more rapid discharge in spite of having more power stored.

Very likely the leakage between peaks is due to corona.

One of the speakers stated that he used less condensance when working at 7000 volts. Is it not likely that this was possible because the voltage was below the corona point and leakage was low.

Dr. Sharp speaks of registering the magnitude of surges with such an instrument, but I believe he will only reach a middle ground in obtaining a surge. The authors state in the paper that "if it does not build up on the first cycle it will on succeeding cycles." Sometimes the surges which come along are very steep, high frequency, and very quickly damped, so that if the first impulse is not enough to charge the electrostatic voltmeter and condenser, the following impulses will not be enough to raise the charge to the voltage of the first impulse.

The current through the condenser at the instant of a surge should be of the order of amperes instead of milliamperes. The kenotron current is limited by space charge and by temperature of the filament, so the condenser cannot be filled on the first impulse. Also with any appreciable damping constant, the succeeding peaks of the surge will not charge the condenser to the voltage of the first peak.

The multiplier method with two or more condensers in series with the electrostatic voltmeter in parallel with one unit would not divide the voltage by ratio during the surge transient, even if there were no current limitation of the kenotron, for if the voltmeter is to store a charge there must be an equal charge displaced in the opposite direction in the series condenser because a d-c. component of current cannot flow through the series condensers.

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The ratio of series condensers has also been found to be wrong unless the several units are guarded by the principles which Mr. Fortescue presented before the Institute some time ago, and unless corona is prevented on any but the outside terminal of the end condenser.

The resistance multiplier is also open to the same objection and errors will result unless capacity to ground and between sections is eliminated by electrostatic shielding.

With the kenotron used on the high-tension side of the transformer as shown by the authors, it must be capable of standing twice the peak voltage, for on the reversed half cycle the charge of the condenser and the transformer voltage are in series adding. It therefore seems that the scheme, measuring crest voltage, would not be very simple on voltages above 100 or 200 kv.

I was very much interested in the test results given in Prof. Work's paper, and I may add I have seen very much worse distortions in testing waves which, I think, will give greater errors with a volt coil. We have tested out the voltage per turn through the secondary winding under various load conditions. In one case I remember the voltage in a secondary turn was reversed in a certain part of the leg from what it was in others. This means that if the volt coil is to be accurate it must be perfectly coupled with the secondary, or must be placed in the average position. The average position depends on the nature of the load, because there is a shift of leakage reactance between the two coils.

Our experience with the volt coil has not been very satisfactory due to improper placing and the resonance of upper harmonics between the load and the leakage reactance of the secondary. However, the results shown by Prof. Work indicate that the volt coil is quite reliable when crest factor corrections are made.

Clayton H. Sharp: I evidently did not make it clear that these experiments were all made on low voltage, that is to say, the instrument itself, the electrostatic voltmeter, was graduated to read a maximum of 250 volts. So questions of huge condensers etc. do not apply to these experiments. The crest voltmeter as we worked it out was used on voltmeter coils, tertiary winding of the transformer, and one side of it was grounded, so that the whole thing was practically at earth potential.

There is no reason why it cannot be used on a condenser multiplier, and I do not quite see why the multiplier needs to be a whole string of condensers. It can be one high-voltage condenser, and in series with it another one of large capacity connected to earth. Thus one condenser takes the bulk of the voltage drop, and the other one, of larger capacity, takes a small portion of the voltage drop and the crest voltmeter is looped about that. Then the indications of the crest voltmeter will depend on the ratio of the two. While I cannot speak from actual experience, I do not see any reason why it should not work, and I do not see any reason why Mr. Chubb's condenser bushing could not be used as the high-voltage condenser.

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With regard to the measurement of high-frequency surges, etc., what we have in our paper is simply offered as a suggestion, and is not backed up with any very positive statements, because we have not the data or the experience on which to rest them. In our paper we say: " In conclusion, it may be noted that the arrangement given offers possibilities in the matter of the study of surges." It may do it, or it may not do it. It looks to me as if, while it is rather improbable, that the full value of the first peak of the high-frequency surge would be given, at the same time the arrangement might be of a good deal of value, even if it did not give the whole thing. Undoubtedly, with a surge there would not be the same building up effect that there is with a steady alternating-current, because the first peak is the one that counts, the oscillations being damped out rapidly after that.

It will be noted, however, that if one kenotron has not a large enough saturation current to catch the surges perhaps two or three or more in parallel may have.

When commercial instruments are available by which the crest values of waves can be measured as readily as the effective values now are, we shall avoid a lot of trouble, escape a lot of mysterious things which occur in high-voltage testing and increase the accuracy and the worth of such work.

C. F. Harding: One very important feature of high-voltage measurement which has not been touched upon in the foregoing papers is the establishment of a more satisfactory primary standard than the combined needle and sphere spark gaps. That these are not entirely satisfactory is freely admitted, for they are subject to correction for barometric changes and in practise it is found very difficult to make the two standards coincide within the range between 30 kv. and 50 kv. where both are standard. Tests covering a large voltage range such as is required upon a line of pin type insulators or upon varying numbers of suspension units in a string are difficult to make when a double standard involving variable and uncontrollable factors is used.

Whereas the meters described in these papers are designed and intended for intermediate or secondary standard use and must be referred to the needle and sphere gaps for calibration, it may be of interest to reconsider the principle of the electrostatic field with a view toward its use as a high-voltage standard.

If, for example, a uniform electrostatic field can be maintained at the center of two horizontal circular metal plates of a relatively great diameter as compared with their distance apart, and if a small circular disc be cut from the center of the lower plate and supported upon a float just below the plane of the lower plate in a tank of liquid, the force required to raise this disc to the level of the lower plate can be readily calculated in terms of the voltage impressed between the plates. With the plates near together this voltage may be small and therefore accurately determined by other means than the spark gap. If

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the field is maintained uniform by applying higher voltages between the plates as they are separated from one another, the force necessary to hold the movable disc in the plane of the lower plate will be constant and the voltage will be directly proportional to the distance between plates.

Such an electrostatic voltmeter has been constructed at Purdue University by Messrs. B. S. Wright and H. R. Holman under the direction of the writer and readings at low voltages confirm the theoretical straight line relation between voltage and distance between plates. This line extended may be used within the limits in which no corona forms for a standard of voltage, the particular instrument constructed having a range of 180 kv.

It should be noted that such a meter would indicate effective volts and that the crest voltage would be determined only after the wave form was known. However, since the crest voltmeters are equally restricted in determining effective voltages and since the latter values at high potentials are becoming of more importance as the losses in dielectrics are being studied quite as much as break-down voltages, further steps are being made to perfect the details of this instrument with the hope that it may be seriously considered in the future as a standard for high-voltage measurement.

W. D. Peaslee: Referring to Fig. 1 of Mr. Chubb's paper it must be recognized that the arrangement as shown will give satisfactory indications only on steadily maintained voltage conditions, as the instrument intrinsically gives a deflection that is some function of the entire wave or series of waves and will indicate an entirely unknown function on a portion of a surge which lasts in terms of cycles rather than seconds. For this reason the indication of the instrument is a measure of maximum voltage only when it is calibrated and used on a particular wave form. What is needed is an instrument that will indicate the maximum voltage applied regardless of wave form and even when this maximum is a combination of a normal frequency (60 cycle) voltage and a superposed high-frequency wave or transient.

It has been shown[4] that the voltage stress imposed on a system by the combination of audio and radio-frequency voltages is substantially the sum of the individual stresses imposed by the individual voltages.

It is therefor necessary in high-voltage testing that an instrument be developed that will indicate at the moment of failure, the actual maximum stress on the medium under test whether consisting of a steady 60-cycle voltage, a transient or a combination of the two. The sphere gap, as has been shown by Prof. Ryan and Mr. Peek gives a fairly reliable measure of the stress resulting from any of these combinations but it is in difficulty of

4. Sustained Radio Frequency High-Voltage Discharges" by Harris J. Ryan and Roland G. Marx, *Proceedings of the Institute of Radio Engineers*, presented Sept. 16th, 1915 at San Francisco.

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manipulation that this device fails in most cases rather than in a failure to give on break-down an accurate indication of the maximum stress, as intimated by the author.

The only device that seems at present to show distinct promise in this line is the cathode-ray cyclograph which, when properly handled will meet to a remarkable degree the requirements mentioned. The indications of this instrument are of maximum values and the calibration is easy. The duration of a surge measurable by it is dependent on the ability of the eye to catch the lengthening of the voltage line and it is hoped to develop a means whereby the eye may be replaced by an electric or chemical device and thus greatly shorten this interval.

As an indication of the extent to which this superposition of normal and high-frequency voltages may affect the results indicated by an instrument of the type described by the author we have found it possible, in the high-tension laboratory to subject an insulator to a stress just under flashover at 60 cycles and hold this stress on it indefinitely without puncturing the insulator. However, when besides this voltage at normal frequency we subject the insulator to a high-frequency stress consisting of several trains of damped high-frequency waves resulting from an arcing ground on the artificial line to which the insulator is connected it will be punctured with a very few applications, if the high-frequency stress is great enough. The instrument described in Mr. Chubb's paper will not give a reading that is a known function of the actual stress that punctured the insulator, but would indicate a lower maximum voltage than that under which the insulator actually failed.

Also the error mentioned in the discussion of Fig. 5 in the paper is a double one as the meter will not only integrate all the positive current areas and neglect the negative ones but will in the next half cycle, which should be entirely eliminated, integrate these negative areas. Thus the meter will read high by twice these negative areas. It will also be in serious error when applied to a wave consisting of a normal frequency wave with the superposition of high-frequency trains or surges.

Referring now to the paper by Messrs. Sharp and Doyle it is very probable that the charge will require several succeeding half waves. Also the fact that the instrument will not recede from it's maximum reading for an appreciable time after the application of the maximum, this time depending on the leakage of the equipment, may introduce serious errors in determinations made with this instrument. Suppose a test is required of 60,000 volts for one minute and that on bringing the voltage up the first few cycles, enough to complete the charge, this voltage was 60,000 but that it then dropped to 50,000 volts. The instrument, until leakage had permitted it to drop back to the lower voltage, would indicate that the required voltage was applied to the insulator while in reality it was subjected to 60,000 volts for a few cycles only and for the rest of the minute to only 50,000 volts. This might result in the acceptance of defective material.

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This effect will be more serious the quicker the charge is built up and the less the leakage.

Also the use of the instrument as a surge trap is open to question until it is shown that the charge is built up in the time of the surge duration.

While these two papers are very valuable additions to the field of high-voltage testing and investigation, it would hardly seem that there was sufficient proof of the value and reliability of either method to accord them a place in the Standardization Rules at present, because of their inherent limits and also because it is quite probable that the cathode ray tube will be developed into a practical form for measuring these maximum values of voltage, both of normal frequency and transient wave trains and of the two combined. As at present available it is much more satisfactory as a maximum-voltage measuring device than either of the instruments described and its failure on transients is due only to the inability of the eye to catch the record of the transient. If any change is made in the Standardization Rules the cathode ray tube should be carefully considered and given its rightful place as a means of measuring maximum-voltage values.

L. W. Chubb: Mr. Peek spoke of the errors due to corona. With the single condenser in series with the crest voltmeter there would be no error from corona, because you are measuring the voltage which is impressed upon the condenser. It does not matter how much corona there is, the line will supply all. If there are several condensers in series, the corona on and charging current of intermediate steps will cause an error except with the condenser terminal or with other similiarly guarded scheme. Each layer of the terminal is in its proper equal-potential surface, and there can be no corona, except possibly around the hat. These terminals will run to very high voltage without any corona at all, on the intermediate steps.

Mr. Peek spoke of the cost of such crest voltmeters going up as the voltage increases. I might add, with reference to the crest voltmeter described in my paper, that the cost goes down as the voltage increases. The condenser terminal is either a feature of the transformer, or it may be a roof bushing. As the voltage goes up, there is more current through the same condenser, and it takes less sensitive and cheaper instruments to measure it.

Mr. Farmer asked about the variation of capacitance of the condenser terminal. That is covered in the paper. It increased from 4 to 5 per cent from very low voltage up to 25 per cent over voltage, but this causes no error, as the crest voltmeter is calibrated in parallel with the spark gap and the variation is, taken care of in the calibration.

M. G. Newman: In the third paragraph of Mr. Hendrick's paper the statement is made: " For precise results at all loads and power factors, it is necessary and sufficient that the ratio of the flux linkages of the voltmeter coil and the high-voltage winding be a constant." This is done by the proper design and

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placement of the voltmeter coil. I would like to explain the method of determining the accuracy with which the above condition is realized.

Referring to Fig. 6, transformer (*A*) is the transformer with voltmeter coil under test. Transformer (*B*) may be a potential transformer or any transformer which can be used to step-down to a secondary voltage which can be easily measured.

Voltmeter (1) is connected to the voltmeter coil of the transformer (*A*) and voltmeter (2) is connected to the secondary of transformer (*B*). Excitation is applied to the low voltage winding of the transformer (*A*). First a reading is taken at no load, voltmeter (1) and voltmeter (2) being read. Various loads are applied at (*C*) (either capacitance or inductance), the voltage and frequency being maintained constant and readings being taken on both voltmeters. The accuracy of the voltmeter coil is good if the ratio of the voltmeter (1) reading to voltmeter (2) reading remains constant from no load to full load.

We do not have to depend upon the accuracy of ratio of trans-

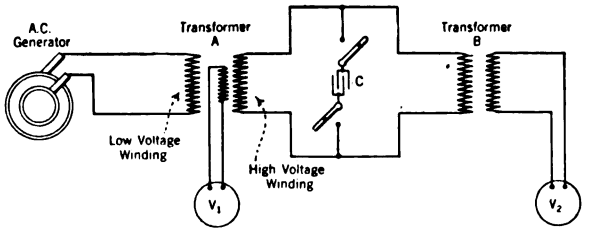

FIG. 6—METHOD OF TESTING THE ACCURACY OF VOLTMETER COIL

former (*B*). The assumption is that the ratio of this transformer will remain constant while tests are being made.

Errors due to flux leakage between the voltmeter coil and the high-voltage coil are shown to be very small.

A full capacitance load makes a small error in one direction and an inductance load an error in the other direction but with correct design these errors can be kept well below one per cent.

A. B. Hendricks, Jr.: I heartily agree with Mr. Peek in his final conclusion that "the voltmeter coil with crest voltmeter and supplemented by a sphere gap to detect oscillations offers the best arrangement for general commercial testing."

A crest voltmeter designed on the principle recommended by Sharp and Doyle, and connected to a voltmeter coil, has been constructed by Mr. Newman, and found to be in every way most satisfactory.

As it is built for low voltages and connected direct to the voltmeter coil, all parts are small, simple and inexpensive. In practise, the indications have been found to be correct and reliable.

Of course, this gives the crest value of periodic waves only, and does not indicate single transients of short duration.

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As stated by Mr. Peek, the voltmeter coil reproduces the wave form in the high tension winding with such fidelity that there is no necessity for connecting static voltmeters or rectifiers directly in the high tension circuit, which is fortunate, since instruments designed for the extreme voltages contemplated have usually been unsatisfactory.

The method of using rectifiers, a condenser and a direct current voltmeter as described by Mr. Chubb is more complicated and less accurate on distorted waves of certain classes than the scheme described by Sharp and Doyle. It is not correct on multiple peaked waves, and the accuracy of the indications is absolutely dependent on the frequency. Neither of these objections applies to the scheme described by Sharp and Doyle, which is in other respects much simpler also.

Of course, every precaution should be taken in designing a transformer with a voltmeter coil to insure that the indications of the latter will be correct. Apparently, in the transformer referred to by Mr. Chubb, these precautions were not observed, with results as related by him.

As it seems to be difficult to convince the average engineer that the voltmeter coil is practically exact at all loads and power factors, I give herewith the results of tests recently made on a 300-kw., 300,000-volt transformer having one end of the high-tension winding permanently grounded. See Fig. 7.

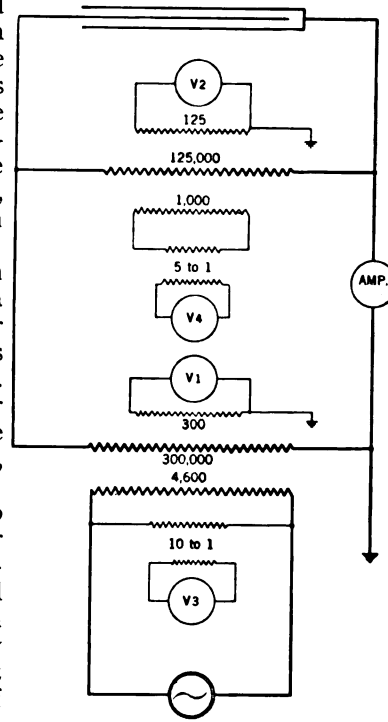

FIG. 7

The transformer was connected to a sine wave generator and the load consisted of a lead covered cable, especially made for use as a condenser.

The potential transformer consisted of another testing transformer rated 25 kw., 125,000 volts with one end of the high tension winding also permanently grounded.

With a pure condenser load it was found that the error of the voltmeter coil was too small to be detected by the best grade of portable dynamometer voltmeters, especially calibrated and interchanged, and read to 1/5 of 1 per cent.

This may be considered a zero error, since it is indeterminate by the most accurate form of commercial instrument, and even the sign of the error is unknown. At the same time the error,

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reading from the low tension winding through a potential transformer was 7.6 per cent or close to the measured reactance voltage of the transformer, as was expected.

Normal rating of testing transformer:
60 cycles, 300 kw., 300,000 to 4600 volts.
Voltmeter coil reads 300 at 300,000 volts.

Normal rating of main potential transformer:
60 cycles, 25 kw., 125,000 to 1000 volts.
Voltmeter coil reads 125 at 125,000 volts.

Ordinary potential transformers of 10 to 1 and 5 to 1 ratio were used on the low voltage side of the 300,000-volt and 125,000-volt transformers.

Test was made at 60,000 volts and 0.88 amps. in the high tension circuit, the normal rating being 300,000 volts, 1 ampere.

The *absolute* variation of high-tension voltage from the winding ratio depends entirely on the magnitude and phase of the current and the *per cent* variation at 60,000 volts is of course five times normal.

The exciting current of the 125,000-volt transformer at 60,000 volts is so small that its effect on the power factor of the load can be neglected.

V_1 = actual reading on voltmeter coil of 300,000-volt transformer.

V_2 = actual reading on voltmeter coil of 125,000-volt transformer.

V_3 = actual reading on low voltage side of 300,000-volt transformer through 10 to 1 potential transformer.

V_4 = actual reading on low voltage side of 125,000-volt transformer through 5 to 1 potential transformer.

Amperes = actual reading on ammeter in 300,000-volt circuit
= condenser + step down transformer currents.

The normal rated voltage of each winding is given on the diagram of connections.

The readings given are from the actual indications of each instrument after correction in accordance with the special calibration of each.

After taking one set of readings, the voltmeters were interchanged as indicated, and a second set taken.

Normal voltage.....	300	125	4600	1000
	V_1	V_2	V_3	V_4
Reading at 0.882 amps....	60	59.9	57.16	96.3
	V_1 & V_2 interchanged		V_3 & V_4 interchanged.	
Reading at 0.879 amp...	60	60	57.16	96.3

These readings were repeated and checked many times, with no appreciable difference in results. All taps on the voltmeter coil gave similar results.

One volt corresponds to two divisions on scale, one-tenth

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division being the extreme limit of observation, and probably beyond the accuracy of the instrument, or observer.

The voltages from transformation ratios of low voltage windings and potential transformer are as follows:

V_3 = 37,300 volts
V_4 = 60,200 "

The high voltage as determined by all the readings is therefore:

V_1.....60,000
V_2.....59,900—60,000
V_3.....37,300
V_4.....60,200

Voltage was fairly steady, but as each observer had to read two instruments, the observations are hardly reliable to 0.1 volt. Other readings of V_4 gave 60,075 volts.

The greatest care was taken in reading V_1 and V_2 on the voltmeter coils, the low tension voltage being of less interest. The small potential transformers may also have slight errors. The voltmeter coil in the 125,000-volt transformer should be perfectly correct, since operation is at half voltage and no load. It is thus seen that the error in the voltmeter coil of the 300,000-volt transformer is zero or so small as to be indeterminate by any ordinary methods, and therefore negligible.

On the other hand, the rise in voltage due to the capacity load is from 37,300 volts (measured on low voltage terminals) to 60,000 volts or 60.9 per cent (22,700 volts absolute).

These results show that the voltmeter coil is certainly accurate within 1/10 per cent, and probably much less on full load, normal voltage and zero power factor leading. It would undoubtedly be equally good on lagging load, but this is never encountered in practise.

Similar tests were made at no load. The following results represent the largest apparent error:

	V_1	V_2	V_3	V_4
Reading at 0 amperes....	59.9	59.8	91.6	95.8

High voltage from above

V_1 = 59,900
V_2 = 59,800
V_3 = 59,800
V_4 = 59,870

From all the readings taken the average error *seems* to be about + 50 volts at 300,000 volts *at both normal and zero load.* This could be produced by an excess of two turns in the high voltage winding of 12,000 turns, or represented by one-tenth of a division on the voltmeter scale.

As a conclusion from all the results it is claimed that the error is less than ordinary minimum errors of observation and instruments, and less than those inherent in any other known method of measuring high voltage.

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DISCUSSION ON "THE TRUE NATURE OF SPEECH" (FLOWERS), NEW YORK, FEB. 9, 1916 (SEE PROCEEDINGS FOR FEBRUARY, 1916.)

(Subject to final revision for the Transactions.)

H. B. Williams: Mr. Flowers has made a definite and valuable contribution to the physiology of speech by showing that in whispered speech the vowel frequencies are very nearly the same for all adult individuals.

His theory that the peculiar curves he obtains at the beginning of spoken or whispered syllables where the first sound in a consonant is due to variations in intensity of the vowel sounds, is ingenious and interesting, but I believe the curves admit of a different interpretation. Such curves could undoubtedly be analyzed into a number of higher frequencies and the fact that in all of the curves of consonant sounds there are marked departures from the sine wave form lends color to the view that higher frequencies may be present.

To record all frequencies of a complicated sound in proper relative amplitude, the recording instrument should have a natural period higher than the highest component by at least one power of ten.

The galvanometer employed by Mr. Flowers for most of his work had a natural period not far from 250 and was critically damped. If the accessory apparatus was arranged so as to give satisfactory amplitude when this instrument was executing forced vibrations at the rate say of 2000, a rate of four or five times that would be almost entirely smoothed out. For this reason I think it unwise to draw too sweeping conclusions from records obtained by this method.

The experiment of running a phonograph at different speeds and securing clear articulation might be also explained by the assumption that the sound is recognized by the association of a number of frequencies which bear a definite relation to each other. No one, so far as I am aware, has ever assumed that the speech sounds were characterized by a definite absolute frequency.

L. T. Robinson: It seems to me in the paper now before us and in a great many previous writings, we have gone too far on the assumption that the electrical wave was the sound wave. There is enough difficulty, perhaps, in recording the electrical wave; but there is a tremendous difficulty, in my own mind, in making that leap from the sound wave to the electrical wave. I have done enough work in this line to convince myself that in most cases the sound wave and the electrical wave are quite different.

Albert C. Crehore: I have had some experience with the galvanometer which has made these records, for another kind of work, a study of the nerve transmission. Here the galvanometer is practically short circuited through the induction coil and for that reason the electromagnetic damping is very great.

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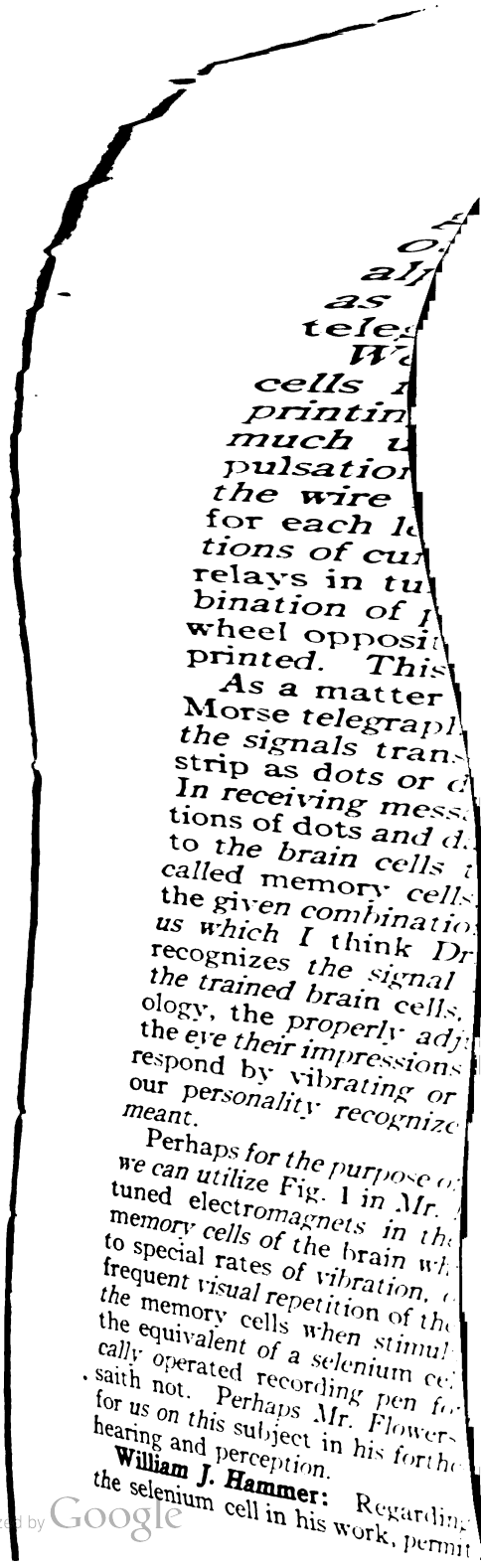
rk I was doing, there are ten thousand, hirty thousand ohms in a little section of the n so that it is a comparatively undamped

which Mr. Flower's work has almost estab- here he has differentiated between whispered olving the vocal chords. The consistency ob- for whispered speech in different individuals, ale, is very striking, and there must be some do not mean to have you understand that the given represent accurately the current or the ily. Whether they do or not, you can com- of them—I mean to say if under similar e a constant result, it has a meaning irre- whether it is a true record or not. In nometer we always take the control, that is, ial suddenly across the terminals and observe ime record. This is invariably done dur- work with the galvanometer, because you ion of the string at a moment's notice. I ontrol curve showing the eondition of the gal- ecords. I assume that the string was slack eriod of vibration, necessarily, because there gy to get results otherwise. But under these ecording forces or vibrations with a string amped, and there would be no over-shooting hould deflect it. Imagine the string at the of the curves, where the force suddenly re- orce had been left on indefinitely, the curve far beyond its base, so that it is not a true that is there at any given moment if we nent with direct currents. The average zero, and so you have a wandering zero. detracts to any material extent from the nake from the records, even though the curve ves as an alphabet may have to be modified.

Jr.: In Dr. William Hanna Thompson's rsonality," in debating the manner in which cles of the body are trained and controlled, ertain instances to which he has referred of les cannot be compared for complexity and raining of the muscular organ, the tongue, ecessary for articulate speech. An animated to make a greater number of rapidly suc- fectly adjusted contractions and relaxations iculation than any famous performer on a Mr. Flowers apparently has accomplished hotographing the rapidly varying vibrations et perfectly adjusted contractions and relax- s of articulation.



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In accord with other writers on the general subject of the fixation of knowledge in the brain, Mr. Flowers expresses his belief that a particular brain cell receives the impression of a given pattern picture. In this relation, Mr. Flowers later points out that when one becomes familiar with the phonographic alphabet he will be able to read it as easily and as intelligently as the telegraph operator reads the signals used in submarine telegraphy.

We might find an analogy to the view that particular brain cells respond to given pattern pictures in the case of certain printing telegraph systems. For instance, the Baudot system, much used in Europe. In this system combinations of five pulsations of positive and negative current are transmitted over the wire for the letter of the alphabet, a different combination for each letter. According to the manner in which these pulsations of current arrive, certain relays will be operated, and these relays in turn will select the letter represented by a given combination of pulsations, by bringing the desired letter on a type-wheel opposite a paper strip, on which the letter is immediately printed. This is termed in the art, selective printing telegraphy.

As a matter of interest, it is quite as accurate to say that the Morse telegraph is also a selective system of telegraphy, whether the signals transmitted by that system are received on a paper strip as dots or dashes, or by audible dots and dashes, so-called. In receiving messages by sound, the ear transmits the combinations of dots and dashes representing given letters of the alphabet to the brain cells that have been trained for this purpose, so-called memory cells, and the brain cells concerned respond to the given combination of signals, and we or the something within us which I think Dr. Thompson would term our personality, recognizes the signal for what it is meant. Correspondingly, the trained brain cells, or as we would say in telegraph phraseology, the properly adjusted brain cells, which receive through the eye their impressions of Mr. Flowers' phonographic alphabet, respond by vibrating or otherwise in such manner that again our personality recognizes the impressions for what they are meant.

Perhaps for the purpose of assisting in illustrating the foregoing, we can utilize Fig. 1 in Mr. Flower's paper. Let us consider the tuned electromagnets in the diagram as the equivalent of the memory cells of the brain which have been attuned or adjusted to special rates of vibration, or otherwise suitably adjusted, by frequent visual repetition of the pattern pictures. Now, whether the memory cells when stimulated by the pattern picture are the equivalent of a selenium cell or the equivalent of an electrically operated recording pen for the interpretation, deponent saith not. Perhaps Mr. Flowers will have some enlightenment for us on this subject in his forthcoming paper on the nature of hearing and perception.

William J. Hammer: Regarding Mr. Flowers application of the selenium cell in his work, permit me to say that while people

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with limited experience ridicule the employment of the selenium cell because of its unreliability, its inertia, etc., I wish to say that I have frequently demonstrated its reliability, and some of its many practical applications, were shown before the Institute at its joint meeting with the American Electrochemical Society on April 17th, 1903 during my lecture on "Radium, Selenium, etc.", at which time I operated 5-h.p. motors and generators, fired cannon, turned lights on and off, talked over a beam of light, etc., by means of selenium cells and an acetylene lamp, and the proper relays and switches.

As illustrating in a remarkable manner the sensitiveness of the selenium cell to sound recording reproductions and transmission, I beg to call the members' attention to Mr. Ernest Ruhmers photographophone which I described at my lecture in 1903, and which I personally operated in Berlin in 1902.

In these extraordinary experiments, when one talked in a telephone transmitter connected in a shunt circuit of an arc lamp it caused the light to vary as a manometric flame. The light beams were passed through a cylinderical lens in the front of a moving picture camera and photographed in striations of varying width and intensity upon the moving film. After the film was developed and put back into the box and the arc lamps replaced (but now burning steadily) the striations on the film acted like slats in a shutter to allow more or less light to pass through the film and to then fall upon a selenium cell in the back of the box. To this cell a pair of telephone receivers was connected, through the intermediary of which the original message could be distinctly heard.

Let me further remind the members of the comparatively recent and entirely successful transmission of pictures through the intermediary of the selenium cell, from Paris to London, across the English Channel, the pictures appearing in the London papers within a few hours.

L. W. Chubb: I have made some tests to check some of the present theories of speech and vowel sounds. The theory of constant frequency and mouth resonance for vowel sounds, was disproved both by the phonograph test, also tried by Mr. Flowers and by the singing of vowels at a note of higher fundamental frequency than the supposed frequency of the vowel. As an example the vowel "oo" is supposed to be represented by the resonance or amplification of harmonic frequencies around 400 cycles per second, and yet the vowel or a word containing it could be distinguished when sung several notes above high C.

The results of such tests and the disagreement between spoken and whispered vowel sound waves, makes me feel that the resonance at constant frequency, although present, is not the distinguishing feature of the sound.

Is it not possible that Mr. Flowers' pattern theory is correct and that the resonance of certain frequencies in certain sounds, is unconsciously produced by the speaker so as to combine adja-

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cent harmonic components in such a way as to get a low frequency pattern or beat?

Comfort A. Adams: Dr. Kennelly has done a large amount of work, both theoretically and experimentally, in analyzing the connection between the vibration of a telephone receiver diaphram and the current producing it, as well as the relation of the deflection of an oscillograph system to the current producing it, over a wide range of frequencies. On the oscillograph end of this work, in which I have been much interested, we have found that the record is fairly accurate up to within a comparatively small percentage of resonance. That is, there must be no appreciable harmonics of that order in the current being measured. Theoretically the problem is extremely difficult when all the numerous variables are considered, but fairly reliable results can be obtained, when the limitations of the instrument are appreciated. Otherwise it is very easy to be badly misled by oscillograph records.

A. C. Crehore: In my remarks upon Mr. Flowers' paper, I had in mind chiefly the application of the string galvanometer for recording such waves as are shown in the illustrations in the paper. It seemed inopportune to introduce a theoretical discussion of the galvanometer in connection with this paper merely because I have worked out the theory of it. There is a great deal to be said about it and of a very complex nature. We have to study nothing less than the complex motions of a stretched string. Think of it if you please as a violin string set in motion not by the bow acting at a single point of the string, but by the magnetic field distributed in some way along most of the length of the string, the force thus being applied to many parts of the string simultaneously and in varying amounts, and we have a partial statement of the problem to be solved.

So, in my remarks, I had hoped that you would accept the statement as given without proofs that the movement of the string under the conditions imposed by Mr. Flowers' problem could not possibly be an exact reproduction either of the waves of sound or of the current in the string, but it might approximate it closely if the conditions were properly met. To have emphasized this point at some length by these proofs would have seemed to detract from the merits of Mr. Flowers' findings, for I believe it to be feasible to obtain results of some value with an instrument which does not record the exact sound waves but yet shows much valuable detail, as this instrument does. We may be assured that if similar results are obtained on the films in different instances the probability is very strong that similar sound-waves caused the records to be alike. This is where I think Mr. Flowers has made a real contribution to our knowledge.

It is my conviction that the records are at best approximations with all existing instruments and this is the reason that a theory of the instruments, is so much to be desired. It tells why the records are approximations and what must be done to make the approximation closer.

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The way in which the magnetic field is distributed along the length of the string is of prime importance in the resulting motions of the string. In instruments as now constructed this field is uniform as nearly as this condition can be readily obtained over nearly the entire length of the string. If the field were exactly uniform the proof is very simple that the curve assumed by the string is the arc of a circle under the action of a steady direct current, no matter how great the deflection. This fact gives rise to certain complex motions of the string, each corresponding to the terms of a Fourier series expressing this circular arc, that is, when variable currents are applied. The simplest possible manner of the field distribution along the string, so far as the resulting motion of the string is concerned, is that of a sine-curve, the field strength being a maximum at the center and tapering according to the sine law towards both ends. With such field the curve assumed by the string under the action of a direct current is also that of a curve of sines, which, therefore, is expressible by the first term only of a Fourier series. The motions of the string under these conditions are the simplest possible, and the complete solution of the motion of the string, for any kind of a current is known. This solution is complex enough, to be sure, but it is safe to use this solution as a basis for making certain deductions, and if it is apparent in this simpler case that the string can not follow exactly such sound waves as Mr. Flowers applies to it, so much the more would this be true for the more complex solution in the ordinary case of uniform field distribution. This solution in the case of the sine-wave distribution of the field for a simple harmonic e. m. f.

$$e = E_1 \cos \omega_1 t = f(t) \tag{1}$$

is, for the periodic portion of the motion alone,

$$y_1 = \frac{H_0 E}{\rho R} \frac{\cos(\omega_1 t - \epsilon_1)}{[(n_1^2 - \omega_1^2)^2 + k_1^2 \omega_1^2]^{\frac{1}{2}}} \sin \frac{\pi x}{l}, \tag{2}$$

where y is the deflection of any element of the string at the distance x from one end of it, and l the length of the string. H_0 is the strength of the magnetic field at its maximum point in the center of the string, ρ the mass of the string per unit of length, and R the total resistance of the circuit, in which the inductance is supposed to be negligible. These and the other quantities in this equation except t are constants, and the equation gives the motion of the string as a function of the time. The phase angle ϵ, is such that

$$\tan \epsilon_1 = \frac{k_1 \omega_1}{n_1^2 - \omega_1^2}, \tag{3}$$

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and the constants n_1 and k_1 in terms of the properties of the string and the air damping factor k are

$$n_1 = \frac{\pi}{l}\sqrt{\frac{T_1}{\rho}} \tag{4}$$

and

$$k_1 = k + \frac{H_0^2\, l}{2\,\rho\, R} \tag{5}$$

When the e. m. f. is a complex function of the time, it is expressible as a Fourier series of cosine terms, and the resulting complex motion of the string is then merely the sum of a series of terms, each similar to (2) in which ω_1 and ϵ_1 take different values, all other quantities remaining the same as before. An easy way to see these results is by means of specific examples illustrated as curves. Since the observations on the string are

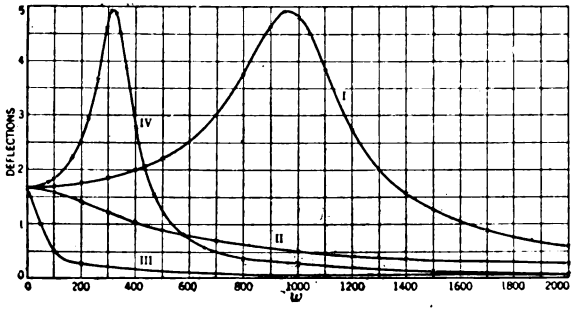

FIG. 1

usually made at its central point, where $x = l/2$, we may first simplify (2) above by making $\sin \frac{\pi x}{l} = 1$, and writing y_0 for y, this meaning the deflection of the center of the string. The curves that are instructive are the relations between the deflections of the string produced per unit of current as the frequency alone varies, keeping the resistance of the circuit constant. Curve I, Fig. 1, is such a curve plotted from (2), showing an increase in the deflection per ampere up to a critical frequency of $\frac{1000}{2\pi}$, and then rapidly falling off for a further increase. The character of this curve is much affected by the particular resistance originally assigned, and the resonance effect is more pronounced the greater the resistance. Curve II represents the same thing, the only difference being that the resistance originally chosen for the circuit is one-tenth of previous value and the impressed volts also one-tenth, the current being the same. Curve III

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shows a further decrease to a one-tenth value in the resistance and volts, the current being the same in the three curves. The resonance effect has entirely disappeared in these latter two curves. From (2) the maximum value of the deflection may be written

$$Y_1 = \frac{Y_0}{(n_1^2 - \omega_1^2)^2 + k_1^2 \omega_1^2}, \text{ where } Y_0 = \frac{H_0 E}{\rho R} \qquad (6)$$

or at the critical frequency, when $n_1 = \omega_1$, this is simplified to

$$Y_1 = \frac{Y_0}{k_1 \omega_1} = \frac{H_0 E}{\rho R \omega_1 \left(k + \frac{H_0^2 l}{2 \rho R} \right)} \qquad (7)$$

And if the damping factor $\frac{H_0^2 l}{2 \rho R}$ is small compared with the

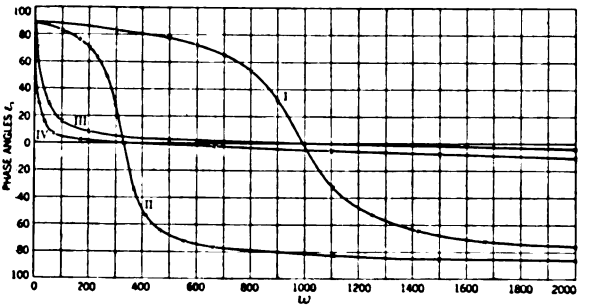

FIG. 2

quantity k, the air damping factor, the deflection at this critical frequency with the same current and frequency is almost exactly inversely as the resistance of the circuit, as is evident in these three curves.

If the value of n_1 is reduced to one third of its value for these three curves by increasing the tension on the string, we would get a curve like IV for the same resistance in circuit as that in Curve I. This shows a much sharper resonance point. The voltage and current for this curve are, however, increased so as to give the same deflection for a direct current or a zero frequency.

Another set of instructive curves are those showing the changes in the phase angle ϵ_1 (3) with a change in the frequency, other things remaining unchanged. Some of these are shown in Fig. 2, Curve I being that corresponding to Curve I of Fig. 1, where the critical frequency is such that $\omega_1 = 1000$ and resistance the same as in that curve. A decrease in the resistance alone will change this curve into one like Curve II. Curves III and IV are a similar pair for the case of greater string tension, III cor-

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responding to IV in Fig. 1. The phase angle is zero in each case at the critical frequency, and changes from 90° at zero frequency through zero to approach −90° at very great frequencies.

We now come to the consideration of the case that applies to the condition of the galvanometer in Mr. Flower's records. The frequencies that he records are far above the critical frequency, which is determined by the string tension, and we are then working at a point on the curves at some distance to the right of the peaks of the deflection curves in Fig. 1. If we had to deal with a single sine-wave voltage alone of varying intensity and definite frequency, the record would give deflections strictly proportional to this voltage, but if the frequency decreased we would get a slightly different deflection for the same voltage. The fact, however, that these curves may change very slowly in height with an increase of frequency when we are far removed from the critical frequency goes to show that the approximation to proportionality may be fairly close over a certain range of frequencies, although it can never be exact.

Similarly the phase angle also may remain fairly constant over a certain range, but this phase angle does not make much difference if we only have to record a single-sine-wave. The making of the record is merely delayed a constant fraction of a cycle behind the current in the string. It is when two or more harmonic forces, that go to make up the complex waves with which we are concerned, are present simultaneously that the phase angle or the time lag becomes important. To illustrate the case suppose there are but two waves and the one double the frequency of the other. The phase lag of each may be very large for high frequencies approaching 90°. This would mean that the absolute shift in time would be twice as much for the slower wave as for the faster, and that their relative shift amounts to one quarter cycle of the higher frequency wave. If the original waves coincided in phase, the zeros of the higher frequency coming at the zeros and the maxima of the slower wave, they never would so coincide in the record, but the zeros of the lower frequency would come at the maxima of the higher frequency. This condition would not give anything like a true record of the original, but it might answer some purposes if one were studying one particular frequency.

Curve II, Fig. 2 shows, however, that this phase lag may not only be fairly constant over a considerable range but that it may also be zero over this range as well. In this condition the relative phases are not displaced and the record should approach quite closely the current in the string in form with the understanding that all the lower frequency waves are magnified in amplitude a little more than the higher ones. So we see that it is possible with a string galvanometer to record a complex wave in an approximately correct form but only approximate. It is evident, also, from the preceding remarks that it will not

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do to calibrate this galvanometer by means of a direct current, and expect that for each deflection observed in the high frequency record the current is the same as that due to a direct current of the same intensity. Curve III, Fig. 1 shows this. The current is the same throughout this curve, and the small deflection at the high frequencies is in great contrast to the large one at the origin where the current is steady. If at any point of the record save where the current is zero one should suddenly maintain the current then existing fixed, the deflection of the string would in general go way out of the field, becoming very large. If, however, you are so well acquainted with your instrument as to know its constants and exactly what you are doing, the calibration with direct currents together with the use of a theory will give the deflections to be expected at any frequency.

I have illustrated this subject by the use of an ideal string galvanometer, the like of which does not exist, and have shown that we may only hope to get a fairly close approximation in any case to the current in the string, and have not said anything about the phase shifting effects of the induction coil and telephone transmitter as being beyond the scope of my remarks. If we should employ an actual string galvanometer, whose magnetic field is approximately uniform throughout the string, the approximation would not be so close as that obtained with this one. In skilled hands this instrument is capable of giving results that can be relied upon, but it is important to know its constants, and to understand the theory of it in order to arrive at those conditions which will give the closest approximation to any desired result. When there is a complete knowledge of these things it is possible to apply the theory to certain records, and correct the records to give the probable true currents in the string.

The curves which I have used to illustrate my remarks are not those which apply directly to the condition of the galvanometer as Mr. Flowers has used it. In his case the electromagnetic damping is the larger of the two, and in these curves I have supposed that the air damping is the greater.

J. B. Taylor: This paper may be discussed from several different points of view:

First, the connection between the nature of speech and electrical engineering.

Second, the correctness of the photographic records offered, as representing the form of the associated sound wave.

Third, the correctness and originality of the theory favored by the author based on these photographic records or on his other data.

Fourth, assuming the theory to be correct how closely may the author's "pattern pictures" for the alphabet from *A* to *Z* be taken to represent the true patterns?

Fifth, can a voice-operated machine be made along the lines described to write definite, readable characters when spoken into?

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The nature of speech is quite as proper a subject for consideration by electrical engineers as any of the problems of telephony, since for perfect speech transmission, there must be exact correspondence between the sound waves produced by the complex actions of the speech mechanism, the mechanical motions of telephone apparatus and also of the transmitted current as modified by resistance, reactance, capacity, permeability and hysteresis of iron, etc. Theoretical and practical difficulties all along the line prevent perfect sound transmission. The telephone user, conversing easily day after day, often fails to realize the dependence which is placed on context and is at a loss to explain the difficulty of understanding proper names, figures and unfamiliar words. Note the changes which have been made in telephone call letters in the attempt to reduce mistakes, and the special telephone language which is springing up to further assist in this direction. Any attempt to improve telephone apparatus and transmission or transformation conditions must have as foundation, knowledge of the essence of speech and a knowledge of the relative importance of the different factors, so that where compromise must be made, the more necessary speech factors will be the least disturbed. These remarks apply as well to " loud-speaking " telephones for train announcing and similar uses, and perhaps with even more force, to the rapidly developing field of radio-telephony where many new devices and remarkable transformations are brought into play.

Regarding the photographic records, it should be borne in mind that these were made with the help of a string galvanometer. While this has high current sensibility, as compared with an oscillograph, its natural period is perhaps 300 or 400 per second against the figures 6000 to 10,000 for the oscillograph. This would call for some correction on all of the curves, and indicate markedly different appearance in those, such as numbers 3, 6, 7, 11, 12, 14, 20, 23 and 25, where the author assigns frequencies of 2000 to 3000 cycles and in the last case up to 5000 cycles per second. No mention is made of the natural frequency of the acousticon transmitter and diaphragm with its connected parts and closely associated air cavity. In my study of sounds and telephone currents with the oscillograph, I have found the form and adjustment of the transmitter, a highly variable factor in the resulting record. For example, in A.I.E.E. TRANSACTIONS, Vol. XXVIII, 1909, Part II, oscillograms are shown, made with different transmitters. Though the records differ greatly in appearance, the inexpert telephone user would probably notice no difference in the receiver.

Bearing on this criticism, Mr. Flowers has replied that the correctness of his records was checked by constructing a selenium cell phonograph and that the reproduced sound was distinguished as being the same vowel or consonant originally uttered. Such a test I believe shows merely that much liberty can be taken with the shape of a sound wave, as is actually done with the

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regular telephone, and still have recognizable speech. I base this statement principally on some tests in which several tandem conversions were made from electric current to sound, back to current and again to sound, with oscillograph examination at the different stages.

Many experimenters and observers have studied the nature of speech and numerous devices have been employed to analyze or record the sound wave. We may mention the phonautograph of Leon Scott, spherical resonators, sensitive flames diaphragms arranged to deflect a beam of light, diaphragms set up as part of an interferometer, motion of soap films, study of telephone currents by resonant circuits, oscillograph, or string galvanometer and by microscopic examination or enlarged transcribing of phonograph records.

Following some of the theories as to the nature of speech offered as a result of these studies and also by independent cut-and-try methods, various attempts have been made to construct machines which under proper manipulation would talk or at least produce one or more of the speech vowel tones.

As regards the consonants, it is quite generally agreed that these are not properly sounds but merely different fashions of beginning or ending certain other sounds. The very name itself, *consonant*, indicates that it is something that goes along *with* the sound rather than being *sonant*, or a sound of itself. Of all the possible speech sounds, there are of course many which are neither definitely vowel nor consonant in character. Mr. Flowers quotes Helmholtz to this effect on the second page of his paper and as far as the consonants are concerned, his records and conclusions appear to be in agreement with the generally accepted view.

The theory of speech, however, about which there has been and still is a pronounced difference of opinion, relates to the vowel sounds and here opinion has been principally divided between what is called the " harmonic " theory and the " absolute pitch " theory.

According to the harmonic theory, one vowel is distinguished from another in the same way as are two different styles of organ pipes, by the number and relative magnitude of partials consisting of fundamental and harmonic over-tones. To demonstrate the correctness of this theory, elaborate sets of electrically operated tuning forks with associated resonators, for controlling intensity of sound sent out from each, have been constructed. Although a great range of tone quality can be produced with such a set of resonators, personally I have never witnessed the apparatus manipulated so as to produce anything fairly approaching a speech vowel. Nor could I produce any of the vowels from a more complete apparatus, consisting of a number of electrical generators in harmonic series with arrangements for controlling the intensity of each.

In the early analysis of speech, it was found that certain

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resonators responded readily to a given vowel tone, more or less irrespective of the pitch of a speaker's or singer's voice. This fact coupled with unsatisfactory results obtained from the series of harmonic forks, brought many adherents to the absolute pitch theory. If pitch alone were the essence of vowels, they should be heard frequently from a pipe-organ or from an orchestra. Such, however, is not the case. I have made phonograph tests (similar to that cited by Mr. Flowers) some years ago and agree with his conclusions on this point. Incidentally and as indicating the great caution which must be taken when using the phonograph to determine the essence of speech or study the quality of a sound, I may mention that Professor D. C. Miller several years ago, at the Cleveland meeting of the American Association for the Advancement of Science, operated a phonograph at normal and at reduced speed to show his audience that one vowel would change into another—in other words to show the correctness of the "fixed" or absolute pitch theory, the indentical experiment which Mr. Flowers cites to demonstrate the incorrectness of the same theory. The difficulty lies in too much psychology in proportion to the amount of physics. Having reason to doubt the sufficiency of either of the prevailing theories, or both in combination, I attempted to get at the root of the matter by observing and recording telephone currents with an oscillograph. The first of these records was taken in 1904 and the reproduction of a telephone current appearing on page 212 of Vol. XXIV of the A. I. E. E. TRANSACTIONS for 1905, is the earliest publication of such a record that I am aware of.

My records are not closely comparable to those of Mr. Flowers's paper for reason that he has limited his discussion to whispered sounds, whereas I gave attention principally to the sustained open vowels. Of these, the starting point is naturally the *A* (as in *far*.) This is the vowel which is produced by the voice mechanism with the muscles in the normal or relaxed position. It is the vowel on which the baby naturally cries, and it is extensively used in our vocabulary, as also in that of every other language. This sound however, does not appear among Mr. Flower's photographs nor in his alphabet of pattern pictures. This is because our alphabet is largely a series of arbitrary names for certain written or printed characters which in turn, in use may have any one of several different sounds. A more complete phonetic alphabet would have instead of 26 letters, approximately twice as many sounds of which, without going into the fine shades of pronunciation, some 14 or 15 would take the place of the present 5 character names for the open vowels.

I have previously described the sound *A* (as in far) as consisting of a series of relatively high frequency vibrations following a "curve of intensity." In the case of my own voice the vibrations proper come at the rate of 720 per second with an intensity cycle following a fairly definite curve at the rate of around 100 per second. The 720 cycles are subject to little or no control, while the 100

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cycles (which is the *pitch* of the voice) may be lowered or raised to the pitch I may desire to speak or sing without materially changing the 720 cycles. Three typical oscillograph records with the voice differently pitched, are shown in Fig. 3 and 3a. If curves of this character are analyzed, as is frequently done by Fourier's series, the fundamental is practically absent and a long list of harmonics each with a particular phase relation is needed to approximate the record. Some experimenters have maintained that given a tuning fork for each of the harmonics shown by the analysis, that the vowel sound could be produced synthetically, but this I doubt unless special means were provided to secure also the definite phase relations indicated by the analysis. Furthermore, it appears probable that the 720 cycle vibrations are not always regularly continued from one intensity cycle to the next, so that the harmonic series of tuning forks could not be made to match the voice vibrations in this respect. The situation is analogous to the damped wave trains of spark telegraphy. The spark frequency may be 120 cycles per second (there being, however, no radiation of wave-length corresponding to this frequency), though the tone which is heard is of the spark frequency and the actual vibration frequency is not sensed. Other vowel sounds may be similarly though not so simply described. If the essence of the vowels is an intensity cycle recurring with a rapidity which we distinguish as the pitch of the note, it is evident that we have something here quite distinct from the harmonic theory or the absolute pitch theory.

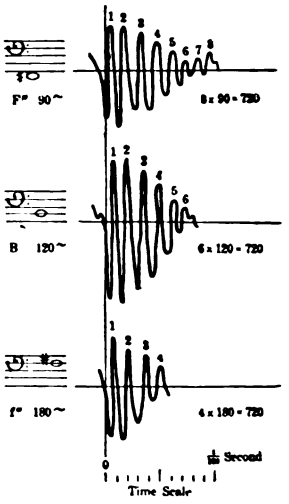

FIG. 3A—COMPARISON OF OSCILLOGRAMS OF VOWEL "A" AT THREE DIFFERENT PITCHES

I have regarded the " curve of intensity " as determined principally by the form of opening, and character of vibration at the vocal cords. Thus, in the case of the vowel *A* discussed, the opening is rather sudden and the closing gradual, which regulates the admission of air in such a manner as to cause the production of 720 cycle vibrations from throat, mouth or nasal cavities. In other words, the vocal cords are not the seat of the sound vibration but a throttle valve in a supply pipe. In this explanation, I differ from what Mr. Flowers offers where he speaks of the mouth and the behavior of the mouth muscles as producing his patterns in the case of a sustained vowel.

The best evidence which I have for my opinion rests on stroboscopic observations of my own vocal cords, pitching the voice to the period of intermittent illumination of the rotating strobo-

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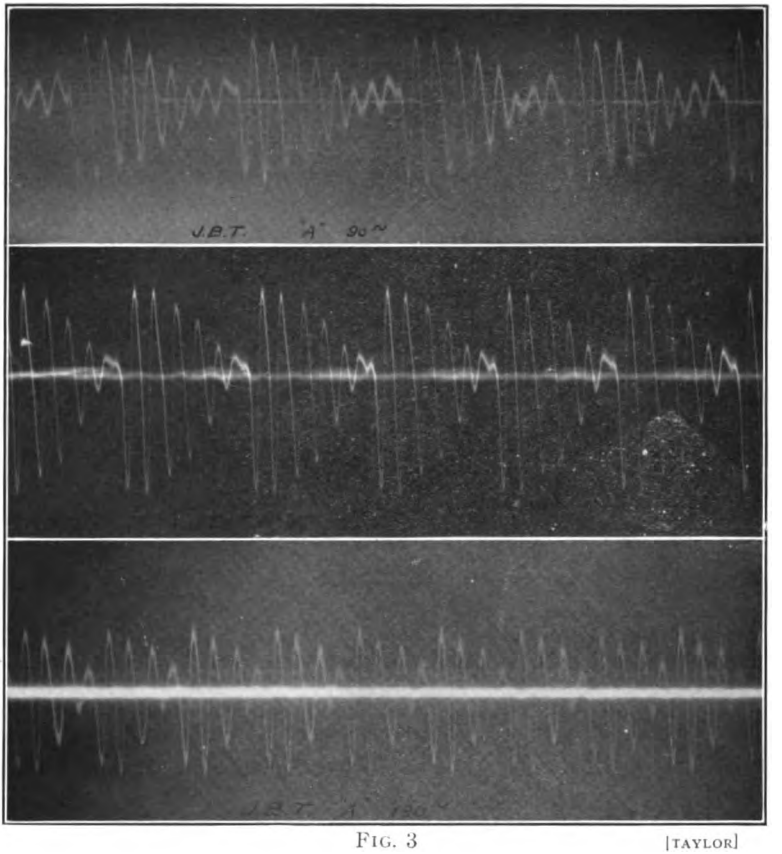

FIG. 3 [TAYLOR]

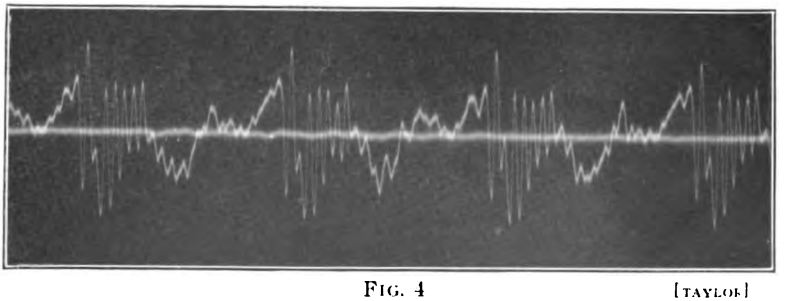

FIG. 4 [TAYLOR]

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scope. Referring still to the vowel *A*, the vocal cords were seen to be vibrating at 120 cycles per second (the intensity frequency) instead of 720 cycles (the principal sound vibration frequency as disclosed by the oscillograph.)

The stability of the 720 cycles for my own voice on the vowel *A* might appear to lend support to the fixed pitch theory. However, at the same time and with the same apparatus with which these records were made, my wife's voice showed a characteristic 960 cycles for the same vowel. For this vowel Helmholtz assigns 1096 cycles. Also my records for the vowel *i* (as in pique, and more familiar in English as *ee*) Fig. 4, show pronounced vibrations at around 2000 cycles which is in fair agreement with the 2500 figure given by Mr. Flowers in his *ee* sounds. For this vowel Helmholtz gives 2322.

I do not see the justification for taking these records with whispered rather than with voiced sounds. While no special training seems to be required for whispering or for understanding the whispered word, perhaps too much is taken for granted in relying on such records as basis of design and construction of machines to operate with *voiced* words. The essential distinguishing physical features may not be the same. I made some observations with whispers but felt that the hissing and breath sounds were confusing and tending to conceal the essential data sought.

I see no reason why study and training may not enable one to read the spoken word from some form of photographic or other sound record, but such a record would have to be many times longer than a line of type corresponding to the same words. I have given some consideration to a visual device whereby a trained deaf person might see the word spoken by another, but fear such a reading is almost impossible of attainment, judged by the speed at which a printed page can be read. Similar time and space objections would appear to hold in a voice-operated machine of the type outlined by Mr. Flowers. If the paper cylinder rotates fast enough to make the consonants easily distinguished, the vowels and pauses will use up yards and yards for even moderate length sentences. Is there any marked saving in space, and why should his special form of record produced by resonant circuits, controlling mirrors and selenium cell, be as accurate or any more easily deciphered than a continuous record such as would be given by combination of telephone and oscillograph?

The problem is a fascinating one and Mr. Flowers is not the first to design devices nor to attempt the construction of apparatus. The earliest definite attempt in this line which has come to my notice, is that of Barlow about 1874. He called his device the "logograph" and arranged an India rubber diaphragm about $2\frac{1}{4}$ inches in diameter to draw a line on a moving strip of paper. Deflections of about $\frac{1}{2}$ inch were obtained as the apparatus was arranged. See *Journal of the Society of Telegraph Engineers* (England, vol. VII, 1878, page 65).

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John B. Flowers: Many interesting and valuable suggestions have been added to my paper on "The True Nature of Speech," and I have considered them all with deep interest. To answer them fully and with the hope that the reply would be conclusive and definite, is not possible until after the completion of the voice-operated phonographic alphabet writing machine. With a set of pattern pictures of the speech sounds as produced by this machine, it will be possible to definitely establish such important points as were brought up by Dr. Williams and Mr. Chubb, that certain of the vowel sounds may be pattern pictures or low-frequency beats produced by combining resonance tones of nearly the same pitch. I note with satisfaction that the main idea of the paper is pretty generally accepted, viz., that the speech sounds are each represented by a special pattern or form picture as shown in the table called the phonographic alphabet. How absolutely necessary it is that a form picture of the sound wave should be the means of distinguishing the different alphabet sounds one from another, is well put by Mr. Taylor, when he explains that, if a definite fixed pitch stood for an alphabet sound we should often hear the speech sounds when listening to an orchestra.

In reply to Mr. Taylor's interesting statement regarding the formation of the vowel sounds as being determined by the form of opening, and character of vibration of the vocal chords, I have personally learned by stroboscopic observation of the vocal chords of several persons by the assistance of a throat specialist, that the vocal chords are absolutely quiet during the *whispered* vowel A (as in far), the same vowel tried by Mr. Taylor. This then proves that the formation of the vowel A sound is not determined by the vocal chords but is due to either the natural coming together of certain resonance tones of the throat, mouth, and nasal cavities, thus forming low-frequency patterns or beats, or is an intensity variation controlled by the muscles of the lungs, throat and mouth, utilizing a muscle tremor. In this connection, it is important to note that the muscles of the human diaphragm and lungs are mainly controlled by the phrenic nerve and are operated by nerve impulses varying between 30 and 100 cycles per second. The inference can be drawn that when the air is expelled from the lungs by the diaphragm muscle in forming a vowel sound, it comes out in intensity pulses of a definite shape and period corresponding to that of the nerve impulse. I am quite sure that this is the explanation for the intensity variation of such a simple sine wave curve as that of the alphabet sound O, curve No. 17.

In answer to the query why the special record obtained by the voice-operated machine of my design would be more condensed and more easily deciphered than a combination of telephone and oscillograph, I submit the following illustration. Assume that the word *boat* is spoken and it is to be recorded in the phonographic alphabet. This is the phonetic word bōt. The

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time required for utterance is (for ordinary speech) approximately b in 1/50 second, o in 1/4 second, and t in 1/25th second. Let the cylinder of paper for the record rotate at a speed of 3 inches per second; then the pattern b is 1/16th of an inch long, o is 12/16ths of an inch long, and t is 2/16ths of an inch long. The resulting record occupying a space 15/16th inches long in contrast to that of the typed distance of 9/32 inches. Therefore, the record of the voice-operated machine will be 3 1/3 times the length of the corresponding letters if typed. It is evident that the combination of telephone and oscillograph only writes down the compound speech curve *without analyzing* it into its elements and the resulting record has been found so complex owing to the compounding of different tones and their variations in intensity, that it is practically impossible to decipher it. But the voice-operated machine would have the power of writing down in the form of the phonographic alphabet the variations in intensity of any of the speech-tones which operate the resonating elements of the machine *after analyzing* the compound speech curve into the tones of which it is composed.

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DISCUSSION ON "IRON LOSSES IN DIRECT-CURRENT MACHINES" (LAMME), SCHENECTADY, N. Y., MARCH 7, 1916. (SEE PROCEEDINGS, FOR MARCH, 1916.)

(Subject to final revision for the Transactions.)

H. F. T. Erben: I agree with Mr. Lamme's statements that iron losses may be approximated with extreme accuracy but these approximations must be based upon past experiences. Mr. Lamme calls attention to the extremely distorted wave form often encountered in variable speed motors and instances Fig. 6 of the paper as being a typical case. While the field form as shown in Fig. 6 is a fair representation of the conditions that may be met in a three to one variable speed motor, distortions of greater magnitude will be encountered if speed variations of four to one or five to one are attempted. I have in mind a four to one variable speed motor which at no load and full load and maximum speed had field forms as shown in Fig. 1. It will be noted that at full load the field form was so distorted that there was an actual reversal of flux in the leading pole tip and the flux density at the trailing tip was fifty per cent greater than at no load. When one considers that the teeth in the trailing tip under these conditions are well up to saturation and that the armature teeth are subjected to double frequency, due to the reversal of flux, it is inevitable that there will be extremely high losses. Losses due to distortions of this nature can be obviated by either providing compensating windings or by using very large air gaps.

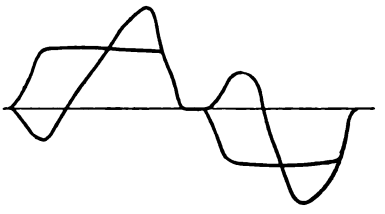

FIG. 1

Generators operating on the multiple-voltage system in connection with mine hoists and rolling mill equipments may have very high core losses under the condition of low voltage and maximum current. The high armature reaction gives rise to an extremely distorted wave form with high peaks. In order to counteract this condition, compensation is usually employed in generators of this type.

Mr. Lamme's paper has only touched upon losses in non-commutating pole machines. In commutating pole machines there is present a loss which is absent in non-commutating pole machines, namely the eddy current loss in the conductors directly under the commutating poles. The flux necessary to produce commutation may be of sufficient magnitude to cause appreciable eddy current losses in these conductors.

Generators and motors in which compensating windings are used are subject to core losses which are not inherent to machines of the commutating pole type. These losses arise through the variations in total flux, caused by the coincidence of the teeth in the armature and pole faces. Although extreme care may be

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exercised in arranging the relative position of the two sets of teeth it is almost an impossibility to get any combination of teeth which will not give rise to slight pulsations in flux. Any variation in the magnitude of the tooth flux will give rise to eddy current losses in both the armature conductors and in the conductors used in the compensated winding. I have cited these cases merely to show the extreme complexity of the problem which faces the designer in attempting to make a true estimate of the core losses of machines of modern type.

W. S. Moody: Transformers have no such percentage of losses to contend with as Mr. Lamme has shown us to exist in the case of generators and motors: yet the stray losses in a transformer are by no means negligible.

Most of the different kinds of stray losses which have been mentioned, exist to a minor extent in a well designed transformer and may easily be of a serious amount in a poor design.

If a given quality of sheet steel is made up into a ring shaped core, each lamination perfectly insulated from the others, the minimum loss that possibly can be obtained will result from alternating magnetization. Just as soon as one departs from this simple elementary form of magnetic circuit, the losses increase. The ring cannot even be made into a rectangle of the same cross section and mean length without an increase in the losses. If there are joints either interlocking or butt, increased losses come from the more or less cross flux that results. Again, cross flux gives stray losses when there is a different cross section in different parts of a transformer's core.

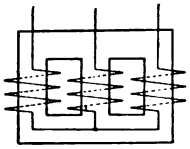

FIG. 2

A transformer core may have another kind of stray loss when the core carries multi-phase magnetization. In the common form of three-phase core as shown in Fig. 2, there is developed in parts of the core not covered by the windings multi-phase flux of a rotating character, which very greatly increases the losses in the iron in this part of the magnetic circuit.

The absence of air gaps and the fact that cores can be built without machining, are the principal reasons why the stray losses are less in transformers than in other apparatus.

Assuming the loss in a ring of laminations, which are perfectly insulated to be the minimum that can be obtained with a given grade of iron, transformers having a simple magnetic circuit can readily be built in which the stray losses are not more than 5 per cent, but when complex magnetic circuits are used and three-phase magnetization introduced, the stray losses in a transformer may readily run to 15 or 25 per cent of the normal losses.

Transformers also have stray losses in the copper, but unlike generators and motors, have stray copper loss only as the load comes on, as there is no flux in the wire space, except as result of the load currents.

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Small transformers with small conductors have a negligible stray loss in the copper, but it is difficult in large transformers to keep the loss within a negligible amount, and in poorly worked out designs, the stray copper losses may readily reach such figures as have been mentioned for stray losses in generators.

Wm. B. Potter: The efficiency of electrical apparatus is certainly a subject worthy of most careful analysis. As Mr. Lamme has pointed out, there are often eddy losses of considerable moment other than those strictly chargeable to the magnetic circuit. The copper conductors, under conditions which are favorable to the generation of eddy currents, may in themselves have losses, which result in a temperature rise quite out of proportion to that from the useful current for which they have been provided. An extreme case I recall was a railway motor with armature conductors of unusual depth running in a field of high maximum intensity, and with the original solid bar winding the local current in these conductors was sufficient to cause a temperaature rise equal to that calculated for the energy current under full load. The remedy in this case, as mentioned by Mr. Erben, was to slit the bars so as to make narrow strips of that part within the core, and criss-cross these strips midway the length of the slot so as to balance the differences of potential between the top and bottom of the conductor. Desirable as it is to improve the efficiency, it is often essential to keep the losses at a minimum because of the heating that would otherwise result, and this is especially true in electrical apparatus where space is of the utmost importance as is so often the case with railway motors. Probably more is required of a railway motor for its corresponding size and weight than any other electrical machine. The space is limited in width by the gauge, in height by the clearances between the vehicle and the track, in length by the wheel base, and it is fortunate that the maximum requirement has a limitation in the coefficient of adhesion between the driving wheels and the rail. The limitations of space for the railway motor are not only severe with respect to heating, but also the design is so compact, so surrounded by running gear, and operated under such adverse conditions that effective ventilation is a much greater problem than with stationary apparatus. A departure from the enclosed design of motor, depending on its external surface for radiation, to later types in which the armature is so designed as to act as a fan giving forced ventilation, has resulted in great reduction in weight and size for corresponding duty. In some classes of service where the conditions are not favorable to inherent ventilation, the use of external blowers as a supplementary feature has been found essential. It is most important that the losses should be eliminated so far as possible, and next of importance is to effectually deal with the losses that cannot be disposed of.

Friend H. Kierstead: Mr. Lamme in his reference to eddy current losses did not bother us with a statement of the peculiar-

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ities and erratic characteristics of these losses. I would like to touch upon the erratic characteristics of eddy current losses with reference to a transformer.

Let Fig. 3 be any conducting material being cut by magnetic flux. Then an eddy current will flow as is indicated in this figure. We can think of this conducting material as being the secondary of a transformer. Now, if its resistance be very high, it acts the same as the secondary of a transformer that is open circuited. If its resistance be very low, it acts the same as a short circuited secondary. The losses in the material due to the eddy currents will be affected by the flux density, by the frequency, by the shape of this conducting material and by its specific resistance. Eddy current losses are equal to $\frac{E^2R}{R^2 \times X}$ where E is eddy voltage, R is the resistance of the eddy circuit, and X is the reactance of the eddy circuit.

Now if the density of the flux that cuts the conducting material in Fig. 3 is changed, then, inasmuch as the only thing that is affected in the above formula by the density is the voltage, the eddy loss will increase with the square of the density, because the voltage is directly affected by the density.

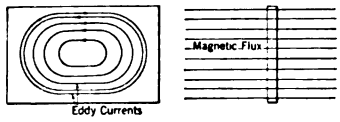

FIG. 3—PLAN AND END ELEVATION OF ANY CONDUCTING MATERIAL BEING PIERCED BY A VARYING MAGNETIC FLUX

Now, if the frequency be changed, then the corresponding change in the loss depends upon the relative values of X and R. If X be very small, as compared with R, the loss is equal to $\frac{E^2}{R}$ and an increase in frequency will increase the voltage, but will not affect the resistance. Therefore, when the reactance of the eddy circuit is small in comparison with its resistance, the eddy loss varies with the square of the frequency.

Take the other extreme, letting the resistance be very small as compared with the reactance, then the loss $= \frac{E^2R}{X^2}$ in which the eddy reactance and the eddy voltage vary with the frequencies, to the same extent. In this case, the eddy loss is not affected by the change in frequency.

An illustration of the former case is in the laminations in the iron of the transformer where the reactance of the eddy circuit is very low and the resistance is comparatively high. An illustration of the second case is in the short circuited transformer where the resistance of the winding is very low in comparison to the reactance, and in this case the losses in the winding do not change greatly with the frequency.

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Let us consider now how these losses change with the dimensions of the conductor. Let the conducting material in Fig. 3 become greater in extent, in such way that the flux cutting it also increases. Then the eddy voltage increases as the conductor increases, and so also does the reactance to the same extent.

Now, if the reactance is small in comparison with the resistance the loss $= \frac{E^2}{R}$ and since the eddy voltage increases and the resistance decreases with increase in the cross-section of the conducting material, the eddy current losses increase greatly as the cross section of the conducting material increases.

Now, if R be small in comparison with X, the loss $= \frac{E^2R}{X^2}$ and E and X are increasing together, and R is decreasing. Then the eddy losses are decreased by increasing that conductor.

The eddy losses are influenced by the specific resistance. If the specific resistance of a given conductor is changed without changing anything else, then neither the eddy voltage or the

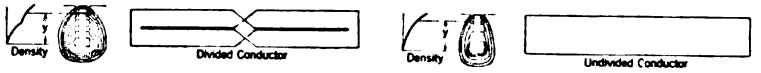

FIG. 4 FIG. 5

DIAGRAMS OF FLUX DENSITY

reactance is affected. Therefore, if the reactance be much greater than the resistance, the loss $= \frac{E^2R}{X^2}$ and the eddy losses increase with increase in specific resistance directly, but if the resistance is great in comparison with the reactance, then the loss $= \frac{E^2}{R}$ which shows that eddy loss is decreased by increasing resistance.

Departing from above analysis, and taking up the divided conductor in the slot-wound machine. Reference was made to a d-c. machine. Fig. 4 shows such a divided conductor in a slot.

In a d-c. machine where the eddy loss in a conductor is not created by the current which flows through it, but by flux which is independent to a great extent of the current in the conductor, this dividing reduces the loss, but in the case where the eddy current is produced by flux, which in turn is produced by current flowing through the conductor, dividing the conductor may not reduce the loss. Let the field produced by current flowing through the conductor be as indicated in Fig. 4. Now if the conductor were not divided, as is indicated in Fig. 5, then the

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greater portion of the current would flow in the top of the conductor and the average density of the flux cutting the conductor would be reduced. However, since the conductor is divided, the same amount of current has to go through the bottom as goes through the top. Therefore, inasmuch as half the current is forced to stay down near the bottom of the slot then the average density is greater than in the undivided conductor and the difference increases with frequency, and therefore the loss in the divided conductor may be greater than it would be if it were not divided, providing the frequency be high enough.

While working under the direction of Mr. H. M. Hobart, we had a problem to increase the loss in an induction motor at starting so as to get greater starting torque, and we actually made up test models to test the losses in the divided and undivided conductors, and we found when the frequency was low the undivided conductor gave greater loss, but when the frequency was high, the divided conductor gave greater loss. It depended upon the depth of this conductor and the frequency. As I remember, when we made the conductor three inches deep, and had 60 cycles flowing through it, the divided conductor gave greater loss.

H. M. Hobart: Mr. Lamme brought out very clearly that there is an irreducible minimum of inaccuracy in predetermination of characteristics. For instance, he mentions in his paper that two machines built on exactly the same specification, with exactly the same tools, may vary in core loss by 20 per cent.

If Mr. Lamme's paper had not been confined to a discussion of iron losses, if he had touched on commutation, or on regulation, or on the predetermination of temperature rise, or on anything of that sort, the limits which he would have shown for the irreducible minimum of inexactness would probably have been expressed in larger figures than 20 per cent.

Mr. Lamme's assertion relating to 20 per cent inexactness was with respect to the no-load core losses, and he pointed out that it was not exclusively the iron loss, but that there were often also losses in the copper conductors which were included in that expression.

It is a fact that in the completed machine these no-load losses are almost always at least three or four times the loss (reduced to loss per ton) which would be obtained in a test made on a laboratory sample. Transformers constitute an exception; in their case there is no such large multiplier, but even there we do not get down to the losses measured on the test samples.

In machines where the greatest care is taken to keep these losses down, for instance, in induction motors, the multipliers are not so great as in other types.

Mr. Potter alluded to the difficulties concerning weight of, and space occupied by railway motors. I have plotted many curves from factory tests to obtain the factor by which to multiply the laboratory loss (the loss of the test sample), in order to

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obtain the loss in the actually completed machine, and that multiplier was larger in railway motors than it was in any other kind of machine. In induction motors the multiplier is reasonably low. In a-c. generators it is decidedly high. These statements relate to the no-load losses.

When we come to the load losses, the observed idiosyncrasies are, of course, all really based on physical laws; such as those to which allusion has been made in the paper; absolutely simple physical laws always being obeyed; but there are so many of these laws that we cannot keep track of them, and at load the losses are often much greater than we estimate. The simple old fashioned efficiency, in which we placed so much faith, is often distinctly higher than the efficiency realized in practise. It is simple enough to measure the efficiency to almost any degree of accuracy, if there is money enough available to spend on the test, but in commercial transactions you cannot arrange for tests that cost as much as, or much more than, the machine itself, and we have to resort to empirical allowances for the various obscure losses.

We are all familiar with the new Standardization Rules issued by the American Institute of Electrical Engineers; the American Rules. A prime mover in creating these Rules was the author of the paper of the evening. Mr. Lamme steadily advocated conservatism in the drafting of these Rules. If I remember rightly, the first suggestion of the plan underlying the "Conventional Efficiency" came from Mr. Lamme. He realized that we could rarely make these laboratory tests which would give the true efficiency, and the only reasonable commercial thing to do was to make sensible assumptions for some of these obscure losses, and he always said—"Let us make these allowances large, let us make them such, that as far as we can foresee, they are certain to at least, cover these actual losses," and so we have in the Rules certain allowances, and it has been the aim of the Standards Committee, that the so-called conventional efficiency, following the recommendations of the Rules, will generally be fully as low as the true efficiency at which you could arrive if you were to make the expensive tests which would be necessary.

Mr. Lamme referred to the subject of temperature rise and I believe it is allowable to make further allusion to the matter. The previous Rules were of some use in this respect; they would give us some rough notion of what the temperature of the parts of the machine might be. As the years advanced, we gradually accumulated convincing evidence that the so-called actual hottest spots in the machine were often far and away above the temperature you obtained with thermometers. Mr. Lamme's attitude was: "Let us recommend certain methods of getting at the very highest temperature, make a clean breast of it, let everybody know that these machines are running at such and such a high temperature." Consequently it was necessary to readjust the temperature limits, so as to make things square up.

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That was a very good plan. It recognizes the high plane which should be occupied by engineering.

There is no use in figuring efficiencies higher than they really are. There is no use in employing ideal but unattainable curves in estimating core losses. Let us take a curve which will be sure not to leave us in the lurch. Do not let us employ the ideal curves and say—" This is the predetermined temperature rise in this machine," or " this is the predetermined efficiency of this machine," or whatever it may be, and then never realize such results.

I should like to call attention to a letter which very opportunely reached me today. I thought it was so relevant to this particular subject that I would refer to it. It is from a British engineer, Prof. Miles Walker. He alludes to the A. I. E. E. Standardization Rules, in paragraphs 452 and 453. These paragraphs define the no-load losses. The letter was so appropriate to the paper, and so thoroughly corroborates the general attitude that Mr. Lamme has emphasized, that I thought it would be interesting to refer to it. In reference to these paragraphs Prof. Miles. Walker says:

" Under the heading 'No-Load Core Losses,' of course this refers to all the losses usually included in an 'iron loss test,' and it would be well to have a statement in the Rules that these include all eddy current losses in armature conductors and frame which occur at no load. There is a good deal of evidence on some classes of machines that a *very large proportion* of the no-load losses are not core losses."

William J. Foster: Several years ago an alternator was built that was three or four times as large as anything previously attempted—it was a vertical shaft machine; the weight of the core was great, and the clamps were made much stronger than ever before. The machine was put together with great pressure, to say nothing about the weight of the core itself, which exerted great pressure on the lower part of it. When that machine was tested we were disappointed in the efficiency, as the guarantee had been high and the calculated efficiency was high. It occurred to some of us inasmuch as every element in the design was favorable to a very low iron loss such as narrow slots with respect to the air-gap and reasonable magnetic densities, it might be due to the fact that the core was not really laminated as we thought, and so the second core was put up with considerably less iron in it. This core was tested without putting the regular winding in, but simply a potential coil, so we knew when we had the normal magnetic densities. We found a decided improvement in the loss, something like thirty or forty per cent.

Then we started in to put in more and more iron, and got back to where we were in the first instance. In that particular case we came to the conclusion that we did not know how to insulate our laminations for that kind of work. We then started in to develop a better method of insulating.

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Confining ourselves strictly to the iron losses, I am a great believer in the proper lamination of the poles where we build with open slots and have non-magnetic retaining wedges. There, again, in my experience we have had just as great surprises in the old days as in the case of this core that was put together with too great pressure for the insulation that was used. There is always, in the case of revolving field alternators where it is necessary to look out for the safe mechanical structure, a temptation to use laminations in building up the poles that are too thick to give good results in the matter of the core losses. We have gotten in the way of using core loss constants with reference to the product of several factors, such as the thickness of the laminations, the tooth frequency, the breadth of the slot and length of the air-gap.

In speaking of iron losses, as confused with eddy current losses in the conductors themselves,—an interesting case, came under my observation in connection with a turbo-generator, of about 15,000 kw. which had a current something like 900 to 1,000 amperes, which we had to handle in a single circuit. The problem first came up in connection with a 25-cycle generator which was developed with a certain conductor, that proved to be an excellent machine in all respects, having high efficiency and low heating, the temperatures being determined by temperature coils embedded in the heart of the slot. By a little slip, or a little forgetfulness, you may say, the same conductor was put into a machine of practically the same capacity, but 60-cycles, where there were just three or four factors differing enough to make that second machine an impossible one as far as meeting the temperature guarantees were concerned. The conductor was laminated, with every strand insulated throughout the entire length. The winding consisted of two conductors per slot with connection clips at both ends, which solidified or short circuited all the strands of the conductor. In the case of the 25-cycle machine, the core was relatively short and the pole pitch large. The length of the core represented the e. m. f. or one factor in determining how much current was circulating between the top and the bottom of that conductor, while the total length of conductor represented the resistance or the other factor. The current in one case was two or three times that in the other, and the eddy losses were several times, six or seven times as high in one machine as in the other per unit length of conductor. The consequence was in the first machine they amounted to a reasonable percentage of the legitimate I^2R loss, say 20 or 30 per cent, and in the other case they were so large as to raise the temperature to a dangerous point. A change had to be made in that 60-cycle machine. The 25-cycle machine is still operating,—a number of them,— with very conservative temperatures. That was simply an instance of oversight in designing.

Joseph L. Burnham: As Mr. Lamme has stated the "treatment of core losses is qualitative rather than quantitative and it

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deals with the simpler phenomena only," although these phenomena are of major importance. The value of the paper seems to me not to be so much in the methods of calculation developed as in calling attention to the conditions to be avoided. The calculations are rather complicated for practical work and depend too much upon known characteristics of the material (which cannot be depended on) and also upon experience which can only be obtained from the results of many tests.

The previous speakers have mentioned the advantages to be obtained from the use of compensating windings but have not mentioned that there are other sources of loss induced by these windings which are very similar to the losses caused by variations in flux density as described by Mr. Lamme and represented in his Fig. 2. By the multiplication of the compensating windings made necessary in modern machines of high armature reaction, the space in the pole face becomes crowded so that care must be taken that local densities are not high thus causing unequal flux distributions. Furthermore, the opposing magnetization of the compensating windings and the armature conductors tends to set up a flux around the periphery of the armature so that, to avoid the bunching of this flux at the pole tips, the reluctance of this path should be made high. If the compensating conductors are not placed quite close to the surface of the pole face, there should be narrow slots in the pole face between the compensating conductors and the pole face parallel to the conductors to increase the reluctance around the periphery of the pole face.

L. T. Robinson: I will add one word to cover the point that Mr. Hobart brought out. I think there may be a little doubt in the minds of some of you as to the difficulties of making iron loss tests agree with the losses computed from determinations made on rings or other samples. I do not think there is any difficulty in arriving at an answer, which is as correct as you can arrive at anything where the material itself is subject to so much variation.

You cannot, certainly, predetermine the core losses closer than you can know the properties of the material which you are going to use, and you do not know that very closely. That must be assumed. In cases where it has been possible to know exactly what the material is, it has been possible to get very close. I am sure you could get similar results in other cases, if you knew where the flux went and how much of it went in certain places. As bearing on that point, I notice that certain figures for magnetic flux density have been referred to as 180,000 lines ($B = 28{,}000$). This estimate is much higher than I believe it should be. The assumption is no doubt made that whatever flux goes through the armature is bound to go through the teeth. Under the conditions of use the permeability of these teeth is very low, and no doubt a large percentage of the flux goes through the slots.

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A. S. Langsdorf (by letter): The best determinations of pole face losses and of empirical formulas for their calculation have been made by operating a machine as a motor and subtracting from the input the sum of the other losses. It is well known that a method which involves the evaluation of a relatively small quantity by taking the difference between two relatively large quantities is liable to considerable percentage error even under the most favorable conditions; and in the case of such a determination of pole face loss the inaccuracy is still further enhanced by the fact that the sum of the "other losses" is difficult to determine because it includes such uncertain items as losses due to flux pulsation, brush contact, eddy currents in armature conductors, and distortion of flux caused by armature reaction.

Considerations of this kind led the writer to the conviction that a reliable determination of pole face loss could be made only by a radical departure from previous test methods and by the development of apparatus that would permit the direct measurement of the pole face loss itself. To this end there has

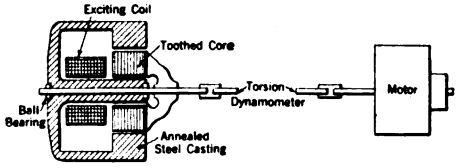

FIG. 6

been designed a special machine built along the lines of a homopolar generator, as indicated in Fig. 6. The frame consists of an annealed steel casting of E section with an exciting coil wound on the central core. In the annular space between the central core and the overhanging outer ring (the pole face) there is centered an unwound, laminated toothed core assembled on a cast iron spider carried by a shaft mounted in ball bearings. The toothed core is driven by an adjustable speed motor through a torsion dynamometer. The only losses that can occur in this machine are the pole face loss and the friction and windage loss; hysteresis is eliminated because of the fact that the core is traversed by a unidirectional, unvarying flux; eddy currents are eliminated provided the flux is uniformly distributed around the gap, a condition that is easy to obtain by accurate centering and which has been shown to exist by careful tests. Friction and windage at any speed can be entirely eliminated by taking as zero reading of the dynamometer that setting which corresponds to the condition of zero field excitation, hence the pole face loss can be read directly.

The apparatus readily lends itself to the following series of tests:

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1. *Dependence of the pole face loss upon average flux density in the air-gap.* In this test the speed of the core is kept constant and the field excitation is varied, the value of the gap induction being determined by the reading of a voltmeter connected through slip rings to a piece of insulated wire stretched across the tip of a tooth.

2. *Dependence of the pole face loss upon peripheral velocity of teeth.* In this test the flux density in the gap is kept constant at some convenient value.

3. *Dependence of the pole face loss upon the slot opening.* For this purpose two interchangeable cores have been provided, one having straight open slots, the other semi-closed slots.

4. *Dependence of the pole face loss upon length of air-gap.* After completing series 1, 2 and 3, the pole face is to be bored out slightly and a new series taken, this process being repeated until the air-gap has been increased to a point where the pole face loss is negligible.

5. *Dependence of pole face loss upon material and construction of pole face.* After the completion of the four series outlined above, the overhanging cast steel pole face will be cut away and in its place there will be successively inserted rings of cast iron, and laminated steel.

Although the construction of this apparatus was undertaken some time ago, a long series of mechanical difficulties had to be overcome before the machine could be made to give dependable results. Work on series 1 and 2 is in progress at this writing. The results thus far obtained indicate that the pole face loss varies at a slightly greater rate than the second power of the gap induction, and very nearly as the 3/2 power of the peripheral velocity, in accordance with theory. The writer hopes to be able to present detailed reports at a later date.

B. G. Lamme: Mr. Erben, in his discussion, has referred to certain pole shapes which reduce flux distortion with load and thus lessen or prevent iron losses due to increase in load. However, the arrangements which he has shown are not suitable for reversible operation, especially where there are liable to be very heavy loads with weak fields. For instance, take reversing mills working on the variable voltage system, where there are frequent excessively heavy currents at almost zero field fluxes. In such machines, as a rule, compensating windings are used to prevent flux distortion, primarily to avoid high voltages between commutator bars and to help commutation. Reduction in armature core loss is not a first consideration in such machines, but the compensating winding, of course, does reduce the loss somewhat.

Referring next to the point which Mr. Hobart mentioned, namely, the desirability of admitting that we cannot calculate certain things in electrical apparatus, with any great accuracy; I have always been a believer in the doctrine that if there are limitations to our doing a certain thing, it is much better to

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recognize such limitations and admit them, and in that way more progress will be made. If we cannot calculate all the losses in a machine with any great accuracy, it is better to analyze them, as far as possible, and find where and why accuracy is not practicable. We should recognize what we cannot do and what the real limitations are and we are then in a much safer position than if we go ahead blindly. For many years the Standardization Rules of the American Institute of Electrical Engineers were very apt to mislead the public. For instance, in the problems of temperature measurements, practically everybody outside of the manufacturing companies thought that accurate temperature determination was a practical condition. One of the great things we did in the last revision of these Standardization Rules, was to show the possibilities of inaccuracy in temperature determination. We openly admitted that temperature measurements as carried out practically, were only approximations, and, in my opinion, in taking this stand we really took a long step forward in the art. The same holds true in regard to efficiency. If we know that we cannot measure it exactly and will tell why we cannot do so, then by so much we advance the art. The same holds true with core losses. However, there is this difference between core loss determination and the other instances just cited, namely, core losses can be predetermined with very considerable accuracy, by what may be considered as empirical methods. These calculations, however, may be considered more in the nature of estimates than true calculations.

The point which I wish to bring out in particular is, that if we know wherein inaccuracies are liable to occur in our calculations, and also know how much the errors are liable to be, in new classes of work in particular, then we are in a position to allow sufficient margin of safety. The difference between experience and inexperience in a designer, is often indicated by this margin of safety.

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DISCUSSION ON "THE INFLUENCE OF FREQUENCY OF ALTERNATING OR INFREQUENTLY-REVERSED CURRENT ON ELECTROLYTIC CORROSION" (McCOLLUM-AHLBORN), NEW YORK, MARCH 10, 1916 (SEE PROCEEDINGS FOR MARCH, 1916)

(Subject to final revision for the Transactions.)

Philip Torchio: The most important results in the findings in these investigations are, first, that with ordinary frequencies of 25 to 60 cycles, the corrosion of underground structures is, practically nil. In this country some of the water companies are still objecting to having the electric lighting companies ground their neutrals to the pipes of the water companies. I think that the results of the investigation of the Bureau of Standards should dissipate any fear of trouble due to the grounding of neutrals to the water pipes.

The next important point brought out by the paper, which should dissipate another fear, is that with potentials in a certain zone changing from positive to negative, which fluctuation may occur in periods represented by the passing of a car with time intervals of possibly five or ten minutes, the corrosion would be negligible.

The next important conclusion to be drawn from the paper is rather astonishing, in so far that only in this year of 1916 a paper of this character should be presented to the railway engineers seriously proposing to ameliorate electrolysis conditions by reversing the polarity of the trolley at certain intervals, as, for instance, of one hour, or a day, or even a week, and showing that by so doing the damage by electrolysis may be reduced to one-tenth, or one-quarter of what it would be by keeping the trolley potential constant, as we are accustomed to do.

Now, this suggestion of reversing the potential of the trolley is not a new one. It cannot be ascribed to ignorance, that this method has not been tried, because as far back as 1902 a Danish engineer, Mr. Absalon Larsen, published in the *Elektrotechnische Zeitschrift* of September 1902, the results of his tests made in the Copenhagen Polytechnic Laboratory; and also a field test, both carried out on practically the same lines as those carried out by Messrs. McCollum and Ahlborn. Making allowance for the immeasurably greater details and completeness of the investigation of Messrs. McCollum and Ahlborn, and also the more complete scientific methods of procedure, it is astonishing that the results obtained in Copenhagen fifteen years ago are in their broad general lines confirmed by the results of the work in the Bureau of Standards.

In Mr. Larsen's paper he states briefly, that the results are as follows: That with one reversal per day the electrolytic action can be reduced to one-quarter, and by one reversal per hour it can be reduced to one-thirtieth of its normal value. From the tables given in to-night's paper we see that the results with one reversal every two days would be in the order of one-quarter,

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and one reversal every hour would be in the order of one-tenth, and it is, therefore, broadly speaking, astonishing that in fifteen years no use whatsoever has been made of the suggestion presented by Larsen.

Two years ago the Joint National Committee on Electrolysis reported on European practise. I made a survey throughout certain of the European countries, and before starting from America I consulted with Dr. Rosa on what line of investigation I should follow, and on his suggestion I had prepared a list of questions to ask every gentleman I interviewed. As a result of all of the interviews I had in England, France, Germany and Italy, I found that this suggestion of the reversal of potential was practically never used. The only places where the potential of the trolley has been reversed were in St. Gall and Nürnberg, but that was done only once, to try to remedy electrolytic conditions. In all other cases practically no application has been made of this suggestion which appears to promise great benefit in many bad electrolysis situations.

Now, I would like to hear from railway engineers why this is so, why this suggestion, which undoubtedly has been known for fifteen years, has never been applied, and then what are the objections to applying it.

Alexander Maxwell: I think the authors of this paper should be congratulated for their investigation of this very practical phase of the general subject of corrosion of underground structures by stray currents, particularly with regard to that part of the investigation which deals with reversing continuous currents, as distinguished from alternating currents of the ordinary frequencies. It is too often assumed that serious corrosion occurs only where the affected structures are close to the rails and positive in potential to them, whereas corrosion is frequently found in the so-called "neutral zones" as well as in locations remote from railway structures, in the latter case corrosion being due to exchange of current between different piping or cable systems, very often associated with reversals of direction.

In one respect, however, I desire to offer a criticism which repeats a similar comment of mine in connection with an earlier paper of one of the authors, namely, that the current densities employed are much higher than those encountered in practise. To be sure, the authors have offered a good reason for the current density employed, but it seems especially unfortunate that lower densities were not investigated on account of the uncertainty which remains regarding the precise nature of the corrosion where low corrosion coefficients were found.

Two examples taken at random illustrate the magnitude of the apparent current densities which may be met in practise, associated with actual corrosion. In one case current having a 24-hour average value of 3.4 amperes, flowed from a 20-inch cast iron gas main between two test stations, 150 feet apart. This works out to 0.0046 milliampere per sq. cm., average, over

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the whole surface. Therefore, only about 1/100 of the whole surface would be conducting to attain the current density used in the experiments described in the paper.

In another case, serious damage was done to cable sheaths by the loss of one ampere in a single section between manholes. Since the cable was of large diameter, it may be assumed that the lowest 1-inch of circumference was in contact with moisture and soil in the conduit, the minimum distance between manholes was about 250 feet. Under these conditions, the contact area would be 19,350 sq. cm., and the average current density would be 0.052 milliamperes per sq. cm., or roughly, 1/10 of the value used in the paper.

I do not mean to say that densities as low as these average densities should necessarily be employed for experimentation, but that something approximating them should be employed in view of the admitted influence of secondary effects which greatly increase the corrosion coefficients at low densities, and which might strongly influence an investigation like the present one. Moreover, it should be borne in mind that the average current densities referred to above may still be directly compared with the densities used by the authors, since theirs are also average densities.

A. F. Ganz: Several papers have been published describing the results of experiments with alternating currents of commercial frequencies in producing electrolysis of iron in soils and in solutions. The results of these experiments have generally shown that with alternating current some corrosion results, but that this is only of the order of one per cent of that calculated by Faraday's law from the quantity of electricity discharged from the anode. The present authors have found substantially the same results with alternating currents of frequencies of 15 and 60 cycles per second. The authors have also included tests using direct current which was reversed at relatively long intervals, the periods varying from one second to two weeks. They have found that even with the longest period of reversal, the corrosion produced is less than that computed by Faraday's law from the total quantity of electricity leaving the anode, and that the corrosion of both iron and lead electrodes decreases with increasing frequency.

The authors have used a current density of approximately 0.5 milliampere per sq. cm. for the iron and also for the lead samples, which is approximately 0.46 ampere per sq. ft. This current density is probably over 10 times as great as is generally found in practise in the case of pipe and cable sheaths affected by stray currents. The authors state that this current density was used because in a previous investigation on the corrosion of iron in street soils, it had been found that with current densities no greater than these, coefficients of corrosion of practically unity were obtained with direct current. I would like to ask the authors whether in the case of lead, similar tests

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were made, and if so, whether with much smaller current densities a coefficient of corrosion as low as 25 per cent was also found. It is well known that as the density of current flowing from a corrodible anode to an electrolyte is increased, a point is reached where, in addition to the metal going into solution, gases are formed so that only part of the electricity is effective in dissolving the anode, and the other part produces gas. If tests with lower current densities on lead samples have not been made, it seems to me that this should be done before the conclusion can be accepted that with lead as an anode the corrosion is only 25 per cent of that calculated by Faraday's law.

The present tests were made with only one kind of soil. It is entirely possible also that with soils containing other constituents than the soil used, a higher coefficient of corrosion may be found for lead.

Assuming, however, that the corrosion from electrolysis with lead anodes is under practical conditions only 25 per cent of that calculated by Faraday's law, it seems to me that this makes alternating or infrequently reversed currents much less advantageous in the case of lead than is indicated by the coefficients of corrosion given for these currents in the paper. To make clear what I mean, I find in Table VIII that with a frequency of reversal of 10 minutes, the average coefficient of corrosion is given as 0.132. This figure is obtained by dividing the actual loss from electrolysis by the loss calculated by Faraday's law. If, however, with direct current the coefficient of corrosion is 25 per cent instead of 100 per cent, the beneficial effect of a frequency of reversal of 10 minutes is represented by four times 0.132 or by 0.528, and not by 0.132. This means practically that if with direct current a certain amount of corrosion is produced, a reversing current having a frequency of 10 minutes will cause a little more than half as much corrosion as the direct current. As it is well known that lead cable sheaths in practise are very rapidly destroyed by localized pitting where they are at all times positive to earth, and even where a relatively small current flows from the cable sheaths, it is evident that much less improvement is to be expected from alternating or from infrequently reversed currents in the case of lead cable sheaths than is indicated by the coefficients of corrosion given in the paper.

The authors state that the reduction in electrolytic corrosion from alternating or infrequently reversed currents appears to be due to the fact that the corrosive action is in a large degree reversible. While the results of the tests indicate that this may be the action, I do not believe that they are sufficiently conclusive to prove this theory, and it would be very desirable to have this phase of the subject discussed theoretically from an electrochemical standpoint. This is to my mind extremely important because it may serve to answer the question as to whether the low coefficients of corrosion found in the present tests may also be expected with the widely varying conditions of the electrolyte found in practise.

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On the basis of the very low coefficients of corrosion found where the reversal is one minute or less, the authors draw the conclusion that where underground pipes or cable sheaths reverse more or less continually in polarity, the algebraic average of the current or potential is more nearly a correct index of the total damage that would result from electrolysis than any other figure that can be obtained. All of the tests described in the paper were however made with reversed currents whose algebraic average is zero. In order to prove the validity of the algebraic average for judging danger from electrolysis, it seems to me that it would be desirable to make experiments in which the algebraic average is other than zero, and particularly with reversed currents in which the periods for the positive lobes are made substantially longer than the periods for the negative lobes.

From a practical standpoint it seems to me that it would also be very misleading to give only the algebraic average of the potential or current, where these quantities continually reverse. This will readily be seen from the fact that large currents may reverse in underground cable sheaths or pipes, and yet the algebraic averages may be zero, so that if the results are expressed only as algebraic averages, an entirely false impression is created. There are other dangers from stray currents flowing on underground pipes and cable sheaths besides electrolysis, as for example fire hazards from sparks or arcing where currents pass through buildings on service pipes or cables. These dangers are not in any sense measured by the algebraic average of the currents.

I want to say in conclusion that if the low coefficients of corrosion found by the present authors, even with very slowly reversed currents, are substantiated for soils generally and for the low current densities usually met in practise, methods of electrolysis mitigation which result in large areas of reversing polarities of the underground structures, such as insulated return feeder systems and three-wire systems, assure a much greater degree of protection from destruction by electrolysis of these structures and particularly of iron structures, than has previously been expected. The work described by the present authors has therefore wide practical application and it is fortunate that we now have the results of this work available.

J. L. R. Hayden: I agree with the author's conclusions except in some minor features.

I do not believe that there is a limiting frequency beyond which no appreciable corrosion occurs. While at 25 cycles, the corrosion is already less than 1 per cent in most cases, there is still a distinct decrease at 60 cycles, and traces of electrolytic action seem to remain even at very much higher frequencies. At the low current densities used in the experiments the chemical corrosion is comparable with the electrolytic, and as the chemical corrosion is very variable, a serious source of error results at these frequencies, which in my opinion is the cause of the apparently negative corrosion at 60 cycles, in Table V.

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I agree with the experience that alkaline solutions chemically protect iron, but attack lead.

The low coefficient of corrosion of lead may be apparent only, and due the assumption of lead as bivalent. As in the lead storage battery the anodic action proceeds to PbO_2, it appears probable that with unidirectional current of long duration, Pb shows valency 4. This would double all the corrosion coefficients of lead. At higher frequencies, lead probably is bivalent, and this would account for the different slopes of the lead and the iron curves.

The observer's results seem to agree with my experience that iron is more erratic than lead. This I explained by the ease, with which iron can assume the passive (probably trivalent) state. As time, current density (even momentary), previous history and nature of electrolyte (nitrates favorable, chlorides unfavorable for passivity) and surface condition (presence of scale) have a material influence on passivity,* during half cycles of long duration the iron electrodes may change from active to passive and inversely. As active iron appears to be bivalent, passive iron trivalent, the previous hydrogen electrode, when changing to anode by reversal of current, would tend to start active. This may account for some of the differences between the odd and even electrodes.

As nitrates and ammonia are frequent constituents of soil, and nitrates have a strong passivating effect, it would have been interesting to make some experiments with soil containing ammonium nitrate for instance.

Also, the action of higher current densities would be of interest, especially with lead electrodes. Lead cables laid in ducts are usually fairly well insulated except locally, where moisture may have penetrated etc. With such lead cables the current flow may be localized, and then higher densities result.

S. M. Kintner: The practical value of the information sought by the author, in so far as it relates to engineering practise in most instances at least, is the assistance it will give in forecasting what will happen to a pipe or lead covered cable buried in the ground and subjected to such electrolytic actions. A pipe, or cable, under such conditions fails by a small hole, or at least only a small hole is sufficient to cause serious trouble very shortly. This being the case it is of rather academic interest to know whether the pipe as a whole has lost one per cent in weight, or even ten per cent.

Even if we knew, quite accurately how the loss varied with current density etc., we could make no practical use of it, in an application such as that assumed, for the very evident reason that we have no control over the current distribution as it goes to or from such a buried pipe. What we are interested in, however, is the order of the loss that may be expected, compared to

* "Electrolytic Corrosion of Iron by Direct Current", *Journal of Franklin Institute*, October 1911.

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that due to d-c. electrolysis, or to ordinary corrosion under like conditions of soil.

The paper contains some very interesting results on the effects of infrequent reversals of direct current. These results are of considerable practical value, if applied with proper discretion.

In a series of tests on a-c. electrolysis made by me in 1904-5 and reported in part in the *Electric Journal* of 1905, attempts were made to secure accurate data. Both iron and lead plates, weighed accurately before and after subjecting them to a-c. electrolytic action, were used.

The plates of iron in some test boxes, and lead in others, were arranged so as to form the two ends of small boxes, of which the other sides were of wood. Some 20 or 30 of these were used in various combinations of frequencies, of electrolytes, of current densities etc. It did not take long, however, to show that the current densities varied greatly, that the "gain" plates of the direct current cells lost as much, or more than those plates subjected to the simple corrosion or to the a-c. electrolytic action and that the cleaning for weighing was apt to produce greater losses than the losses it was expected to detect.

The d-c. "loss" plates would be eaten through at places slightly below the surface, while at other places down deeper in the solution the action was comparatively slight. This was quite conclusive proof that the current densities were not uniform over the whole plate surface. The mounting employed was expected to eliminate the greater density at the edges of the plates and thus secure a closer approximation to uniformity of current density.

It is to be noted that in the present paper no such precautions were taken and so it is reasonable to expect even a greater variation in current density than in the tests made by me in 1904.

After concluding a number of the plate tests, all laboratory tests, and reaching the decision that no data of a greater degree of refinement were obtainable or even if obtainable, could be applied practically, it was decided to check the general observations by tests approximating as nearly as possible, the actual operating conditions. Consequently a number of pipes of about four feet length and three inches in diameter, were buried after being carefully weighed, marked and having their ends sealed with an asphalt gum. These pipes, both commercial wrought pipe and lead cable, were buried in three different localities separated some 25 miles from each other. These test pipes were arranged in groups in each of the three localities and in this way the effects of frequency, current density, (insofar as total current per pipe would indicate it) direct current and simple corrosion were observed. Pipes were buried at different depths varying from two to six feet. There was a sufficient number of pipes in each combination to permit the removal of some after various periods of action. They were all removed at the end of one year.

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Attempts at weighing and checking against the original weights, proved of no value whatever.

A careful study of them did show that effects of the a-c. electrolysis, both 25 and 60 cycle, was just about the same as that shown by pipes subjected to corrosion only.

Fortunately the character of soil, in the three places in which they were buried, differed very materially.

The effects on the pipes of the alternating currents followed quite closely, in each of the three places, that produced by corrosion only.

The serious effects noted were pits, some quite deep, while the pipe immediately adjacent was in good condition with no signs of pit marks. The pits were no different on the pipes subjected to the alternating current than those where corrosion only had caused the action. This indicates either a variation in the pipe, or a variation in the soil in which it is buried, which sets up a very strong local activity.

Carl Hering: The results given in the paper are of interest and of value, especially as some of them are different from what was probably supposed to be the case, while others confirm by experiment what heretofore was a mere belief. One of the most valuable results is that in what are called the neutral districts in underground electrolytic corrosion problems, the periodic reversals of current practically neutralize each other; also that corrosion from underground alternating currents of the usual frequencies, is not a serious menace; there were good reasons for believing that for lead covered cables at least, the corrosion due to underground alternating current might be serious.

Asa P. Way: This paper suggests an attempt made about six years ago for the mitigation of electrolysis in two instances, one of which was very familiar to me. In this method a specially designed transformer was used through the low voltage side of which passed the return current of one or more pipe drainage feeders connected to taps of different potential. The primary was excited through resistance by an intermittent current from a 550-volt d-c. source. The idea was to set up a relatively low frequency reversing potential between pipes and rails. However, financial as well as mechanical difficulties, I believe, prevented the development of the installations although there appeared to be merit in the scheme.

However I have had in mind for some time to use the principles set forth in this paper in connection with the insulated negative feeder system but particularly with such an installation put in operation about two months ago. In this particular installation two of the feeders connect to a track about 4000 feet apart where tracks are consistently negative to water pipes although conditions are not dangerous, due principally to some poor track bonding in the neighborhood. My idea is to place in series with each of these feeders a definite amount of resistance alternately to be short circuited by automatically operated

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contactors. The resistances would be so designed that when one is short circuited and the other is in series with the other feeder and vice versa the potential between pipes and rails at the ends of the feeders would alternately reverse. It might be found that one resistance in series with the return current of both feeders could be alternately short circuited and left in series which would probably increase the area subject to reverse current flow between pipes and rails. The contactors could be operated by a relay controlled by a sign flasher or any other convenient method. I would like to know if the authors of this paper think that would be effective.

C. B. Martin: The tests described in this paper were made in soil. This condition is the usual one that must be considered in connection with standard trolley roads, but in connection with electrified heavy traction roads the effect of reversing currents upon steel imbedded in concrete becomes of importance.

For the last twenty-five months we have had under test units made of one inch steel rods, six inches long, surrounded by two inches of concrete placed in water baths in metal pails. In some of these units the current has flowed in the direction to produce electrolysis of the rod, and in others the same current was reversed at the rate of 0.8 cycles per minute. The resistance of the d-c. units increased steadily, while that of the reversing units hardly at all.

How well the steel embedded in concrete of the d-c. unit automatically protected itself will be seen by the reduction of the current with the same impressed potential. At the start the current flow was 0.08 amperes; in ten days 0.04; in thirty-four days 0.02; in three hundred and twenty-eight days 0.01, and in seven hundred and sixty days 0.005. The efficiency of corrosion for the whole period was 28.4 per cent.

The average current flowing was 0.053 milliamperes per sq. cm. of the surface of the rod, which is about one-tenth of that required to produce the maximum corrosion of iron. This low density is, however, very much above that encountered upon the steel structures in which we are most interested.

An examination of the reversed current electrode showed that it was but slightly affected. Only 0.588 of a gram of metal had been removed, and the efficiency of corrosion was only 0.95 of one per cent of the positive current flowing.

The results of our reversing tests on steel in concrete, therefore agree very closely with the results reported in the paper on reversing tests in soil. In both cases the resulting electrolysis is practically negligible.

Another test which we made in 1912 is interesting. An electrolysis test sample similar to those described above which had been under test for three weeks with a positive potential on the electrode increasing from 12 volts to 52 volts, as the internal resistance of the sample increased, was subjected to a current reversing every minute, and the varying resistance of the circuit recorded.

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See Fig. 1. It will be seen that very promptly upon the reversal of the current there was a surprising drop in the resistance, which was partially restored upon again making the electrode positive. Under repeated reversals the resistance of the sample steadily decreased with every indication that a stable condition had been reached. Finally the electrode was again subject to a steady positive potential and the resistance increased to an approximation of its original value. Naturally the question arises what caused the resistance to increase and decrease in this manner? Was the action due to gases or the expulsion and return of the electrolyte? At any rate the test shows that the resistance of the electrolytic circuit of steel encased in concrete is built up by making the steel positive, and broken down by making it negative.

Electrolysis engineers working to protect underground struc-

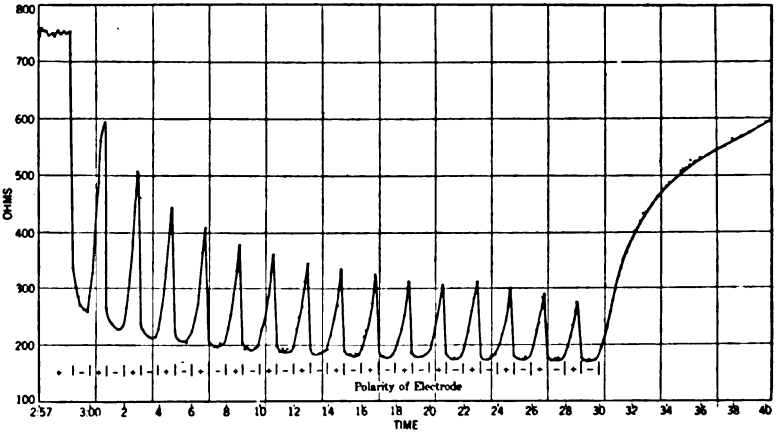

FIG. 1

tures from electrolysis have constantly before them the statement that one d-c. ampere flowing steadily for a year will disintegrate twenty pounds of iron, or seventy-five pounds of lead under favorable conditions. Should such rates of deterioration be realized in practise many important structures would be in need of extended repairs, and the expenditure of very large sums in protective measures would be justified.

When, however, foundations, especially steel foundations encased in concrete have been uncovered and found to be but slightly affected although subjected to a potential favoring electrolysis for years, the question naturally arises whether there are not circumstances which in practise largely reduce these large estimates of electrolysis damage.

The paper of the evening demonstrates the existence of at least one very important condition that materially retards electrolysis in many localities.

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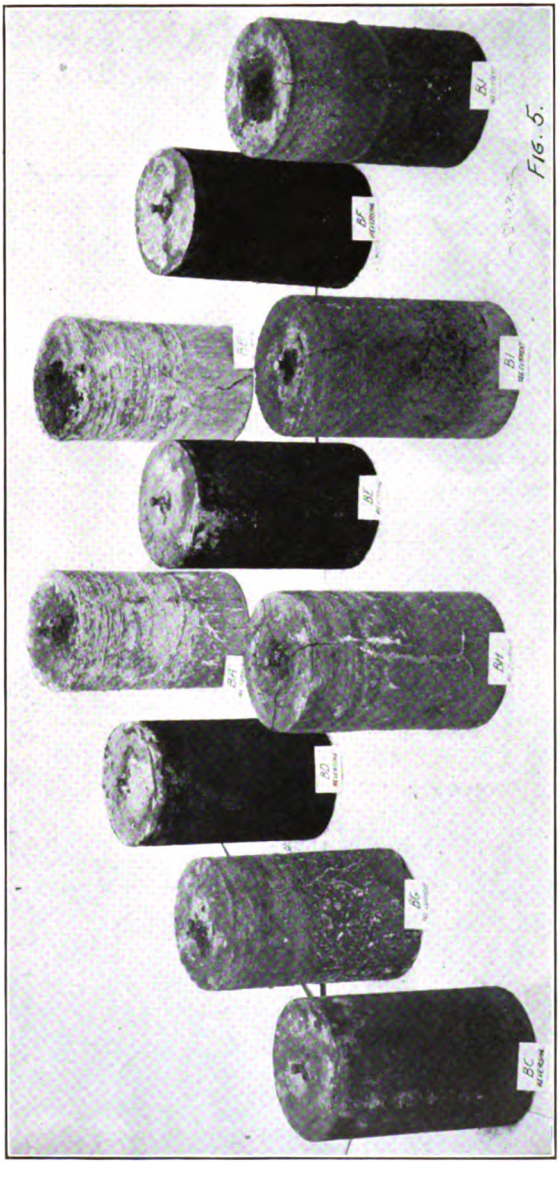

FIG. 5

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An important conclusion that should be drawn from the paper is that in an electrolysis survey, readings should be taken for twenty-four hours, preferably by means of recording instruments so that the full cycle of a day's operations will be included and all current reversals recorded.

We are particularly interested in the statement that the loss of lead in soil under d-c. flow is about 25 per cent of the theoretical loss. We trust that this important phenomena will be more fully investigated and explained. Tests which we have made upon electrolysis samples of steel surrounded by two inches of concrete indicate that the efficiency of corrosion is not over 30 per cent. Some of these tests have extended over long periods.

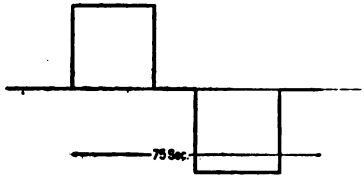

FIG. 2

Referring to conclusion (2) of the paper that "the corrosion is practically negligible for both metals when the period of the cycle is not greater than about one minute," we have understood that when electrolysis is taking place under ordinary conditions that water molecules are broken up and the gases collect at the anode and cathode surfaces. Upon reversal of current, is it not possible that these gases, especially the hydrogen gases, in some way interfere with the prompt starting of electrolysis? May it not take about a minute to dissipate these gases?

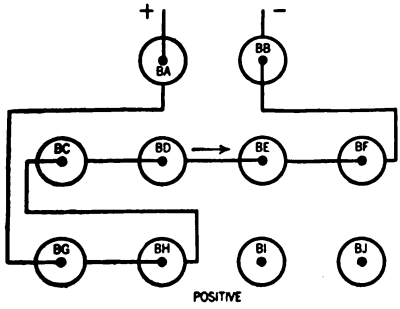

FIG. 3

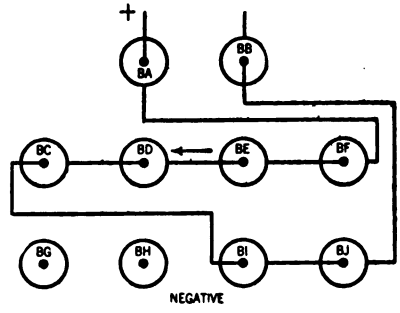

FIG. 4

In the twenty-five months' test referred to above, there was a period without flow of current between each reversal amounting to about one-third of the time. The shape of the current curve is shown in Fig. 2.

In addition to the four samples subjected to reversing test there were six others that were connected in circuit as shown in Fig. 3 and Fig. 4.

In Fig. 5 is shown all the samples at the end of the twenty-five months, each sample being lettered correspondin to its position in Fig. 3 and Fig. 4.

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Thomas M. Roberts: My remarks will be a brief comment on conclusion No. 8.

Fig. 6 represents a rise of potential in a pipe line above a given zero, and a simultaneous drop of potential in the rails with the going and coming of cars. It is to be noted that the change of potential of the conductors in the earth is greater as the distance between the bond points increases. This probably is known to many railway engineers, but it is not so well known to many who install underground systems of piping which may become bonded with electrical conductors. I simply call attention to the fact that in an active zone a well bonded system of pipes and conductors suffers less from electrolysis than a poorly bonded system. This we know irrespective of whether the electrolytic effects are caused by an arithmetical average or by the algebraic sum of the currents. The effect is what it is, irrespective of the name given to the cause. The name is a small matter; the method of installation is the important thing.

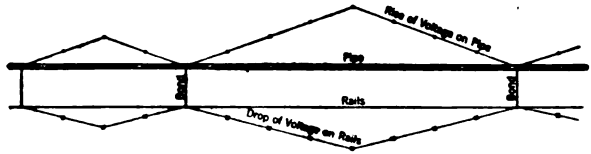

FIG. 6—DIAGRAM SHOWING INCREASE OF POTENTIAL DIFFERENCE BETWEEN PIPE AND RAILS WITH INCREASE OF DISTANCE BETWEEN BONDED POINTS

L. W. Chubb: We carried out about a year ago a test with slow reversal currents. In the control of large induction motors it has become quite common to feed the secondary through a water rheostat, as it is called. The frequency of alternation starts at 25 or 60 cycles, and as the motor speeds up the frequency drops to the slip frequency which is less than one cycle per second.

There has been some corrosion trouble with the metal electrodes in different parts of the country and very careful tests were made to find the effects of purity of water. These tests were carried out not in as much detail as they might have been, but they showed conclusively that the water, although reasonably pure, as pure as the moisture of the soil, has a great bearing on the result. Tests were made from 60 cycles down to 0.1 of a cycle per second, the low cycles being obtained by feeding from the secondary of the induction motor, with a constant slip, and by reversing direct-current with a rheostat which cut in and out the resistance, so that the wave shape approximated a sine wave. The specific results are covered in Mr. Spooner's discussion.

Sodium carbonate is used in water rheostats. It is used because it causes little corrosion. For this reason I believe it was not a very representative chemical to add to the soil employed in the test described in the paper. I think it is

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to be regretted that the authors cleaned their samples as they did, and did not take off the scale before the test was made.

Prof. Ganz said, that the usual current reversals do not have an average value of zero. I might say that it is possible that the average value of the test current was not zero in these tests, which may account for the great discrepancy between odd and even plates, and also increase the results. If the ampere-hours in each direction are equal, we should expect a very much lower corrosion than if there is, say, one per cent increase in one direction over the other. In our tests we met this trouble, and had to make a good many of the tests over again. We used ampere-hour meters to integrate the current first in one direction and then in another.

Thomas Spooner: Almost a year ago we made some tests on the effect of frequency of alternating current on the rate of corrosion of various metals and alloys in solutions of 2 per cent sodium carbonate and in sea water. The tests were largely qualitative, but they may add something of interest to this subject.

The investigation was made on plates of various materials immersed in electrolytes contained in beakers. There was no stirring beyond that produced by the electrolytic action. Each plate had an immersed area (one side) of about 2.7 sq. in. (17.4 sq. cm.) and the average current varied from 5 amperes to 1 ampere, the higher the values being used only on a few preliminary tests. The average current for most of the tests was about 2 amperes. The tests were made with various frequencies from 25 to 0.1 cycles per second. The results are expressed in loss of weight in grams per ampere-hour. Some of the results obtained are as follows:

TABLE I.—ELECTROLYTE—2 PER CENT SODIUM CARBONATE
LOSS IN GRAMS PER AMPERE HOUR

Frequency cycles per sec.	*Ingot iron	Monel metal	Nickel chromium alloy	Current supply
0.1	0.0175	0.0008	0.0021	Reversing switch
0.1	0.0155	0.0014	0.0030	Revolving rheostat
0.2	0.0055	0.00077	0.0030	"
0.5	0.0021	0.00084	0.0017	"
1.0	0.0011	0.00056	0.00078	A-c. generator
5.0	0.00015	0.00011	0.0022	"
25.0	0.000012			Shop supply

TABLE II. ELECTROLYTE—SEA WATER.

0.1	Badly corroded in 3½ hrs.	Badly corroded 3½ hrs.	Entirely eaten away in 1½ hrs.	Revolving rheostat
1.0	0.0041	0.0111	0.0498	A-c. gen.
5.0	0.0022	0.0098	0.0401	"

*Ingot iron was tested in sodium carbonate solution with d-c. It was badly corroded at end of 9½ hours.

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A few tests were made on a 5 per cent nickel steel alloy (rolled), a 5 per cent nickel steel alloy (cast), and boiler plate. The first two corroded rapidly, while the last at frequencies of 0.5, 1.0 and 5.0 and a 2 per cent sodium carbonate solution gave the same results as the ingot iron within the limits of accuracy of the test.

The first 0.1 cycle tests were made with a motor driven reversing switch which was open about the same length of time it was closed. The revolving rheostat tests were made with an apparatus as shown in Fig. 7. The operation of the device is obvious from the figure. It gave a wave like that shown in Fig. 8.

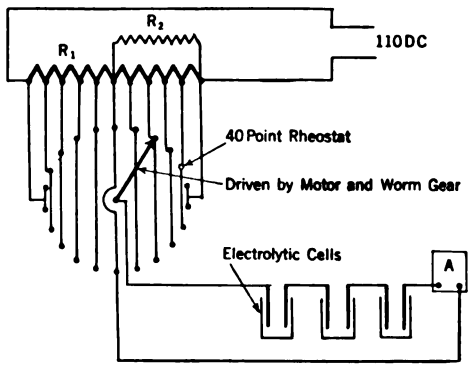

FIG. 7

The resistance R^2 (Fig. 7) was introduced to correct a slight dissymmetry in the positive and negative halves of the current wave. This device was substituted for the reversing switch because it was difficult to make the time of closure of the switch the same for both directions and because for this particular investigation it was desired to have the wave form approximately that of a sine. The average value of the current was determined by an integrating d-c. ammeter which was reversed each half cycle. The ratio between the maximum current and this average was calculated and considered constant for the several succeeding tests. The equality of the positive and negative halves of the current wave was checked by means of a copper voltammeter.

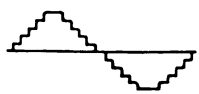

FIG. 8

These tests induced us to arrive at the following conclusions:

(a) The lower the frequency the greater the loss in weight of the electrodes, this loss increasing very rapidly below 0.5 cycles per second.

(b) All of the substances investigated corroded very rapidly with d-c. currents.

(c) Where considerable chlorides are present in the electrolyte, ingot iron seems to be superior to any of the other substances investigated.

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(d) With low frequencies, monel metal seems to be the most satisfactory with 2 per cent sodium carbonate solution.

(e) Boiler iron seems to have almost the same loss as ingot iron.

(f) Very large differences in loss were obtained depending on the condition of the surface of the plates. This may account for the peculiar increase in loss for the nichrome at 5.0 cycles (see Table I) as this material is especially susceptible to surface conditions.

Some previous investigators have thought that the electrode loss per ampere hour was a function of the current density. Where they have shown data to substantiate this, is it not possible that the greater current density produced a stirring action, which as pointed out by the authors of this paper, increases the loss.

Maximilian Toch: Under the heading "Complete Series of Tests," it is stated that the experiments were conducted with iron and lead buried in soils, and I believe no attention has been paid to the electrolyte in these soils, for the obvious reason that if steel or metal which will corrode is buried in a soil in which there is no oxygen nor water corrosion cannot ensue, and I have seen so many cases of subterranean corrosion, beams of buildings, pipes and conduits, that I know there is a vast difference between electrolytic corrosion in a wet soil and electrolytical and chemical corrosion in a semi-dry soil.

In fact, I have gone so thoroughly into this subject that I am even now conducting experiments on the western coast of South America in a climate which I believe is much dryer than that of Arizona, and I have conducted experiments in the southern part of Nevada and the northern part of Arizona on the protection of steel against corrosion under various conditions. I say this in order to qualify before you, for I have paid a great deal of attention to this subject in the last twenty-one years.

Burton McCollum: Mr. Torchio has raised the question as to why the principles brought out in the paper have not been heretofore applied by electric railway interests for the mitigation of electrolysis troubles. The reason I think is quite apparent, namely, that in order to secure anything like the high degree of protection that would be desired it would be necessary to reverse the polarity of the trolley several times a day, although of course, reversing once every 24 hours would accomplish something. To reverse the polarity of the trolley once an hour or oftener would introduce an operating complication that few if any, railway men would consider. Such frequent reversal would be objectionable even where an entire system is supplied by a single station, and would be practically prohibitive in the case of a railway system fed by several interconnected stations. It is largely for this reason I think that the work of Mr. Larsen has not been given more attention. I would point out in this connection that the work described in the present paper covers

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an entirely different field and was undertaken for an entirely different purpose from the work done by Mr. Larsen. Mr. Larsen's object was to determine whether or not it would be feasible to reduce electrolysis trouble by a frequent reversal of the trolley polarity, and he carried out no experiments in which the current was reversed more frequently than once an hour. In the present investigation it was our aim to determine the order of magnitude of the corrosion that would be produced in the so-called neutral areas of railways where the reversal takes place at short intervals of from a few seconds to a few minutes. In order to make the investigation complete we carried out some experiments with alternating currents of ordinary frequency on which a good deal of work had previously been done, and also extended our investigation into the regions of long periods such as those adopted by Mr. Larsen. Between these extremes however, we have covered a wide range which has not heretofore been investigated, namely, frequencies of reversal such as those found between tracks and pipes and other underground structures in the so-called neutral areas of electric railways.

I wish to make it clear that the authors have not put forward this data with any idea that it will be used as the basis of a comprehensive system of electrolysis mitigation, and we do not consider that there is much likelihood of it being used in this way for the reasons pointed out above. Our principal purpose in bringing out the results of these tests is to show that in so-called neutral areas the actual amount of corrosion that will take place is much less than has often been supposed, and that the extension of the neutral areas due to the application of insulated return feeders, three-wire systems, and other methods of mitigating electrolysis troubles, need not be regarded as introducing any additional hazard to underground structures.

Regarding the criticism brought out by Prof. Ganz and Mr. Maxwell, I would say that the current density of 0.5 milliampere per sq. cm. was used for the reason that this is about the lowest value that is likely to be of any practical consequence. If the current density is 0.5 milliampere per sq. cm. the actual rate at which the iron would be corroded away would be approximately one centimeter in 12 years. This is a rate of corrosion which is frequently encountered in practise where electrolysis conditions are only moderately severe. Much higher current densities are frequently found, however. On the other hand, it is perfectly true, as Mr. Maxwell and Prof. Ganz have pointed out, that in practise, especially near the so-called neutral zones, the current density may often be but a very small fraction of that used in the tests, but it must be admitted that such current densities are of no practical importance. For instance, if we use a current density of 0.0046 milliampere per sq. cm., which Mr. Maxwell states has been actually found by him, it would appear that it would take about 1300 years to corrode the iron

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to a depth of one centimeter. While it may be true that the effect of reversed currents with these low current densities may be very different from that observed in these experiments, it is evident that the rate of corrosion in any case will be so low that it is of no concern from a practical standpoint, however interesting it might be from a purely scientific point of view. In this connection I would say that the corrosion on the test specimens used by the authors, while not strictly uniform, was nevertheless so well distributed over the surface that it was evident that the current density at any one point was not very greatly in excess of the average value of 0.5 milliamperes per sq. cm. used in these tests.

Prof. Ganz states that the tests were made in only one kind of soil. This is quite true. Part of the tests were made in the natural soil and some with sodium carbonate added, and the results, while slightly different, indicate the same general law. It is not improbable that with soil from different sources it would be found that the knee of the corrosion curve, or the point at which it begins to rise abruptly, would be shifted more or less. Nevertheless all of the experiments made indicate that the effects would be of the same general character as here observed.

Prof. Ganz quoted some figures from the table and seemed to convey the impression that they are misleading. For example, he stated that the table shows that with a ten minute reversal in the case of lead the coefficient of corrosion given is 0.132, and he appeared to assume that this is intended to show that the ratio of the corrosion on this frequency to the corrosion on direct current would be 0.132. This error might readily creep in provided the authors did not give the actual corrosion on direct current, but since this is given and shown to be approximately 0.25 I do not see how any one could be misled as to the magnitude of the reduction in corrosion produced by the reversals.

Prof. Ganz also suggested that in view of the fact that all of the experiments described in the paper were made with periodically reversed currents in which the algebraic average was zero, that it would be desirable to make additional experiments with unsymmetrical alternating currents in which the algebraic average is not zero. This I think is a good suggestion and I hope that it may be possible to make such experiments in the near future.

Mr. Way described a plan which he expects to try out whereby he hopes to utilize the principles set forth in the paper for reducing electrolysis troubles. If I understand his plan correctly it would amount to superposing on a unidirectional current a symmetrical alternating current of sufficient magnitude to reverse periodically the polarity of the pipe. This would not have the effect of reducing the algebraic average of the current, so that if I have not misunderstood his plan I do not see how it would materially reduce electrolysis troubles.

Mr. Chubb suggests that possibly the positive and negative

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half waves were not equal and that this may in part account for the large discrepancy in some cases between the corrosion of the odd and even electrodes. This seems very unlikely since great care was taken to avoid any error of this sort. An oscillographic record carefully analyzed in a considerable number of cases did not reveal any appreciable unbalance.

I have been particularly interested in the results presented by Mr. Spooner as they were made under different conditions using a liquid electrolyte instead of soil, but nevertheless the results obtained on ingot iron are substantially in accord with the results presented in our paper.

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DISCUSSION ON "ELECTROCHEMICAL INDUSTRIES AND THEIR INTEREST IN THE DEVELOPMENT OF WATER POWERS" (ADDICKS), "WATER POWER DEVELOPMENT AND THE FOOD PROBLEM" (CUSHMAN), "RELATION OF WATER POWER TO TRANSPORTATION" (STILLWELL), WASHINGTON, D. C., APRIL 26, 1916. (SEE PROCEEDINGS FOR MAY, 1916.)

(Subject to final revision for the Transactions.)

David B. Rushmore: As we all know, the world in its advance has been marked by certain definite epochs which have been associated more or less with certain inventions. Unfortunately, not all of these have been recorded in the United States Patent Office, because when man invented power and the use of powder, and the use of fire, the Patent Office was not organized.

It is interesting to see that the civilization which we have in this age is sharply distinguished by certain features, and to my mind the particularly distinguishing feature of this age (which we will say runs back something over one hundred years) is the large use of energy and the great advantage which has followed from its use. Our whole civilization is based on the fact that we consume an amount of energy per individual far in excess of the energy which that individual can evolve.

If we had a complete statement of the facts, we would find that in the last one hundred years there has been an enormous increase in the use of energy per inhabitant. The world, and particularly the United States of America, in the past hundred years has gone through a rapid cycle of activities. Their sequence has been exploration, hunting and fishing, lumbering, mining, agriculture, and finally industry, including manufacturing.

The United States is approaching the industrial age, and that is one of the reasons for some of the economic diseases which we may or may not be able to ward off. The food products are falling off, exports of manufactured products increasing. This indicates a change of flow of commodities.

Now, this being an industrial age, and the age being founded upon the consumption of energy, it is rather interesting to show in brief outline what our principal industries are. At the top stands slaughtering and packing, and it is followed by foundries and machine shops, lumber and timber, iron and steel, flour and grist mills, printing and publishing, cotton goods, men's clothing, boots and shoes, woolen, worsted and felt goods, tobacco, car shops, bread and bakeries, iron and steel blast furnaces, woman's clothing, copper smelting and refining, malt liquors, leather, sugar and molasses, not including beet sugar, butter, cheese and milk, paper and wood pulp, automobiles furniture, petroleum refining, electrical machinery, distilled goods, hosiery and knit goods, and a great many others, in which the value of the annual production is over $100,000,000.

Now, if we withdrew the energy from the world, if we for a moment withdrew the energy from our civilization, we would go down like an infant whose food is withdrawn from it. That

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means that our civilization is dependent on energy, and anything which affects the production of energy seriously affects the continuance of our civilization.

Water-power is one of the sources of energy, fixed as regards location and fixed as regards certain attributes and factors which it involves. Energy we must have for our civilization. And what is the attitude, or what is the relation, of the different factors of chemical industries, of food production, of transportation to the source of energy on which they will draw?

First, the problem goes back to the one which we have often considered, that of conservation. The only way to conserve a waterpower is to use it, and the only way to conserve a coal supply is not to use it. A question that is not often raised, but is involved in all of the papers this afternoon, is the great improvement in steam generating apparatus, both as regards the decrease in cost and the increase in efficiency, but we make a great mistake in making use of the cost of coal instead of the value of coal. If the last ton of coal in the world, the final ton, before we go into something else, cost 80 cents, we can all say that its value will be worth more than 80 cents, so that the value of the coal and oil supply which we are not conserving in any way, in fact, we are now wasting it, by allowing such waterpowers to go unused as might be economically developed cannot be determined by the present cost of coal. We are detracting just that much from some future condition of civilization.

Now, if the government, if a combination of individuals, committed some act which robbed our civilization of some of its food supply, or of some other necessity equally great, or even of some of its pleasures, there would be protest. Just that same cause for dissatisfaction exists against ourselves, for we are all involved, not utilizing in the best way we can the sources of energy which are at hand, and whose use would not diminish their worth, and persisting in the use of sources of energy which may ultimately become exhausted. Take into consideration the per capita increase in coal consumption, increase in commodities, increase in industry and transportation, we can see that it cannot go on forever.

The question of waterpower and its relation to these different energies is this—waterpowers are, some of them, susceptible to present economic development. My personal belief is there are many waterpowers in the United States where power can be developed at the power house for much less than steam will ever be capable of being developed, but water power at the power house is different from water power one hundred miles away. Many of our electrochemical industries could be located at the power house in so far as the simple question of power is concerned. Many plants are already so situated, but in the long run the question of the transportation of materials controls.

I do not place the blame for the lack in waterpower development on any one in particular. As I see it, and under the situa-

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tion as it has arisen, the people do not understand its value. They sit still, until some one devises and works out some practical way of doing things. When the people are educated, so that they can understand what is going on, then they will take action with regard to the development of such problems.

The railway electrification which has taken place in this country started in the East. The first railway electrification was practically forced by legislation, due to an accident in New York, and that has meant that the railway electrification has been largely based on steam power, on energy derived from coal. There has just begun a larger railway electrification. The transcontinental trunk lines have taken up electrification. The Chicago, Milwaukee & St. Paul is the first one to go into the use of energy derived from waterpowers. They are electrifying three hundred miles of main line running through Montana, of which one hundred and thirteen are in operation, and the work has been very successful. Some of the results secured are that the cost has been reduced, the weight of the trains increased, and the speed of the trains increased. Prior to the electrification, a considerable proportion, I do not know the exact number, but I think it was not far from 15 per cent, of the locomotives on the railroads were simply hauling fuel for the other locomotives to use. They have been cut out. One of the greatest dangers on the mountain lines is the braking of passenger and freight trains going down hill, and the life of the brake shoe is very short. With electrical motors there is nothing to wear out, not only is the braking done without mechanical friction, but power is brought back in the line.

The very great likelihood is that this road will soon electrify all the way through to the Pacific Coast, and that will force the other railroads to electrification, and force the utilization of these waterpowers, if there is any way of bringing that about. It will require a vast investment, which the railroads have got to provide. If they cannot afford it, they must attract this investment in order to bring about this use of energy. When this waterpower is utilized there will be a saving of other forms of energy to civilization, a saving of coal, which will not have to be burned up until some time later.

The point which we are all looking at is this—the relation of all these factors of waterpower utilization to our modern requirements of consumption. We must bear in mind that once a waterpower is developed into practical operation its supply of energy is continuous and not diminished by time. Some sources of waterpower energy are sometimes inaccessible, sometimes they are expensive to deliver, and sometimes they have a very intermittent stream flow. In certain cases the waterpower can be tied in with another system, a steam station, which, with the waterpower, will develop power for transmission over long distances. In some cases the waterpower plant cannot be physically or economically separated from the steam plant, as a

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matter of fact, and the question is always before us how best to bring about the most economic utilization of such water-powers and how best to conserve our fast diminishing coal supply.

F. A. Lidbury: There seems to be no doubt from the papers we have heard this afternoon that whatever other applications for water power may be successfully prosecuted in the future the consumption of water power by the electrochemical industry is one that can certainly, given favorable circumstances, be counted upon to grow very considerably. Mr. Addicks has covered very briefly and very concisely the large number of factors which enter into the employment of water power for electrochemical purposes, and the paper is worthy of study because among those who are not closely familiar with conditions in the electrochemical industry it is common to put the whole of the electrochemical industries in one class as power consumers. They are extremely diverse, their requirements in power are extremely diverse, and the relative importance of the factors of power, labor and other items is also extremely diverse.

We have electrochemical industries which have not succeeded yet in obtaining a footing in the United States because their requirements in power are enormous in extent, and because they require the power at a price at which this country is as yet unable to furnish it, and probably always will be unable to furnish it. We have, on the other hand, industries which you could not drive away from this country no matter what the power conditions were, industries such as that Mr. Addicks is associated with, the refining of copper, in which operation the cost of power is such a minor item that they generate the power by steam.

These two classes of electrochemical power consumers, however, stand outside the limits of that group of electrochemical industries which is chiefly located at Niagara Falls in this country. Mr. Addicks inquired why, in view of the fact that the price at which Niagara Falls power is now sold can not be considered low, and in spite of the fact there is a shortage of power at Niagara Falls, these industries do not go to other places. The answer is—they stay there because they are there. Why are they there? Why did they go there? They went there because at the time when these industries were being developed, at the time of their birth, Niagara Falls offered them the most favorable ground which they could select for their development; it offered them a source of power which then appeared to be reasonably large for their needs, a source of power at a cheap price, and a source of power of an extremely reliable nature. To a great extent it is entirely owing to the fact that at the time these industries came into existence that source of power was there in that form at Niagara Falls that these industries now are at Niagara Falls and not, to a large extent, in Europe.

Mr. Addicks inquired why they do not move from Niagara Falls to other parts of the country, particularly to those regions

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where they could obtain power from steam at a cheap price. That brings me to a point which Mr. Addicks might have expressed a little differently. He compares the cost to an electrochemical consumer of water power and steam power, and taking the cost of water power around $20 per horse power per year, which he presumes to be the present Niagara price, compares that with what he conceives steam power can be generated for in large units. In one case he is dealing with a selling price at one's plant including a profit; in the other with an actual cost. The answer to Mr. Addick's question is that these plants have been moving and are moving from the country. Those of you who are familiar with the conditions of the electrochemical industries of Niagara Falls know that when the restriction was put on the power developments at Niagara Falls, in 1906 and 1907, an emigration of electrochemical plants producing materials not for foreign markets but for American markets started and has been continuing ever since. That gives, as far as one can answer the future by surveying the past, the answer to Mr. Addicks' question—Why do the plants stay at Niagara Falls? The answer is they do not, and they will do so, apparently, to a less and less extent. The reason for this is, of course, as everyone knows, that there is at present a power famine at Niagara Falls, particularly on the American side of the border.

The location of such plants at other points in the United States where cheap water power may be available is only possible in the majority of instances where these water powers are most favorably located. I made some calculations a few days ago comparing the cost of water power with the costs of freight on finished electrochemical products. A reasonably cheap freight rate, as you can all appreciate, is vital in the electrochemical industry. It appeared that a thousand mile haul to the center of the area of distribution would be equivalent to a difference in the cost of power, as a rule, of from $10 to $20 per horse power year; in one or two instances much more.

So far as the electrochemical industry is concerned, this question of water power is a vital and pressing subject. Unless the electrochemical industry is able to get the power as it requires it in economically available locations, that industry will relocate, and to a great extent will relocate abroad. By the time you have converted power into electrochemical products, and utilized those electrochemical products, and have figured what it would mean to this country to stop the progress which those electrochemical products have made possible in the fundamental interests of this country, Mr. Rushmore's $100,000,000 a year will look like nothing.

Henry G. Stott: The question that seems to run through all of the three papers might be put in a few words—How can we get power cheaper? Is there any way in which we can develop power cheaper than it is being developed at present, which will admit of the development of the electrochemical processes? If

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we go back perhaps we will see why the electrochemical industries today are tending to move away from Niagara Falls.

Fifteen years ago Niagara Falls was unquestionably producing power more cheaply by water than by any other method which could be found in this country. In the meantime the evolution of hydroelectric equipment has gone on quite slowly, as it had a very high initial efficiency. Let us look, on the other hand, at the steam plant. The hydroelectric plant, let us say, has made 10 per cent advance in fifteen years, but in capital cost it has not made any advance at all, if anything the capital cost has gone up, as the cost of labor and material has run up.

Let us look at the steam plant. To begin with, the capital cost of the steam plant in fifteen years has been a little more than cut in two. The next point is that the steam plant is now making power with approximately one-half the coal required fifteen years ago. Those are two enormous points of advantage.

I was very much interested in going over a situation recently which involved tacking on, as it were, a steam plant to a large hydroelectric system. It fell to my work to look into the economics of the situation as well as the engineering possibilities. After going into the situation carefully I came to the conclusion that up to a certain load factor we can today produce power more cheaply, with a lower overall cost, (including fixed charges, and operating cost), by a steam plant than we can by any hydroelectric plant now in existence applied to this particular case.

The overall costs of power were approximately equal at a load factor of 60 per cent. Above that the hydroelectric plant began to show a little better results than the steam plant. Below that point the steam plant was better relatively as the load factor went down.

Now, what we learn from these facts, is simply this—that if we want to produce power at a lower cost than we can do today by hydroelectric plants, we must use some combination of steam and hydroelectric power, the steam plant for the peak loads and the hydroelectric power for that part of the load having load factors of over 60 per cent.

With this combination, as I found in the investigation referred to, the total cost of power, showed a reduction over what could be produced by either steam power or hydroelectric power alone.

There is one feature that Mr. Rushmore touched on, which it seems the whole discussion should go back to, and which we should present to our legislatures and explain the situation as clearly as possible to them; that is, if we can produce steam for the average purposes, for the use of those industries which involves the use of a load factor considerably below 50 per cent, why bother with hydroelectric power at all? There is no use in going into it where the load factor is below 50 per cent. There is hardly a single hydroelectric power left which it will pay to

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develop if the load factor is below 50 per cent. The conservation of our limited supply of coal, however, demands that every possible means of reducing the annual consumption of fuels should be enforced for the benefit of posterity.

At the time of the last census there were approximately 1,750,000 kilowatts developed hydroelectrically in this country. I wonder if we realize what that means? That means that approximately 20,000,000 tons of coal per annum are saved to posterity. That, it seems to me, is the real point that we should drive into the minds of our legislators if we can,—we should do everything possible to save our limited supply of fuel.

The improvement in the efficiency of steam plants has been remarkable during the last fifteen years, so much so that, as I said before, the total cost of power has been cut in two. I think there is a possibility of going still further, there is perhaps 10 or 15 per cent left to work on with the present cycle, but the important thing, it seems to me, is to stop the use of coal wherever we can do without it, by developing our hydro power. That would look like a good situation for the government to consider in aiding rather than retarding the development of hydro power.

Gano Dunn: The average load factor of all the central stations in the country, including water powers, according to some government figures I recently saw which I trust I interpreted correctly, is under 26 per cent, which drives home the importance of Mr. Stott's remarks about the difficulty of a water power competing in the power market with a steam power when water power is only good, or at its best, at high load factors, and cannot hold its own at low load factors with the present efficiency of steam production.

Those interested in the water powers are keenly desirous of finding some way of getting the cost of power down, in a way that might be regarded as intrinsic, as distinguished from the way Mr. Stott referred to and others have referred to of supplementing the water powers with some auxiliary. An intrinsic way would be the development, of processes that could take secondary power, whose costs of interruption under the secondary power plan would not more than offset the gains due to the cheapness of secondary power.

I hope we can get a full discussion from our electrochemical friends in regard to the degree of interruption permissible, and its economic effect in order that we may study to what extent secondary power can be used to absorb the now wasted surplus power of a great many hydroelectric developments. Such absorption would not only give cheap secondary power but would have a reaction reducing the cost of the primary power; in other words, both services would be considerably reduced in cost.

Mr. Stillwell significantly points out the changed equation between steam power and water power in application to the electrification of railways. It is unfortunate that three-quarters of our power consumption is in the east and three-quarters of our

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potential water powers are in the west, but if we want to do something about the water power situation, and do it promptly, without going into the realm of doubt, there is a large amount of work cut out by attacking those situations where the water power is actually cheaper than steam power on account of the high cost of fuel, and where the railways would benefit enormously by using such water power as is available. One reason they have not used it in the past has been quarrels among electrical engineers as to which system of equipment was the best. These questions are very rapidly settling themselves. The railroad men, who are conservative, have been deterred from adopting electrical systems, not knowing how soon they might be changed. In introducing electrification upon the railways it has required large amounts of capital, and capital has been difficult to raise in the last decade on account of rate regulations and similar restrictions, as well as on account of the general attitude of the public; and the railways have felt that it would be better to "suffer the ills they have, rather than fly to others they knew not of." It is for us to show that this time has passed, and that the time for the more general electrification of the railways is at hand.

If those interested in water powers, and if those interested in the electrification of railways, especially in the Pacific and mountain states, will devote their energies to bringing the various interests and engineers together, so that there may be mutual understanding, we can at least make a good start by using such water powers as at present can be used to advantage. Once we started, there would be indirect advantages of electrification that will start a general movement and will show that these indirect advantages have, perhaps, been underestimated, and there will then be equipped with water power many railroads which now think they are not quite ready for the equipment.

J. B. Whitehead: It has been emphasized that the cost of electric power from steam plants has been decreasing while that of power from water plants has remained practically stationary. The explanation lies in the general low efficiency of steam plants, offering, therefore, opportunity for improvement and also the lower first cost due to the development of the steam turbine.

The question arises—would it in any way be possible to improve the showing of the hydro-electric plants in the same directions if efforts corresponding to those exerted in the steam problem were also directed to the water plants? While improvements in the efficiency of water power plants, comparable to those possible for the steam plant, may not be looked for, it should be possible, in certain types of plants, to reduce the first cost of the station. Savings should be possible in an aggregation of electro-chemical industries and a water plant in which the generating station would operate at moderate voltage and with the elimination of high tension control and protection. It would also appear not impossible to have the generating station

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under these circumstances, practically of an out of door type, with such simplified control as would be necessary, located in one of the industrial plants. While this does not attack the larger cost of the dam and reservoir it seems to offer some opportunity for further reduction of cost of the station.

L. H. Baekeland: The standpoint of the chemist or electrochemist can be summed up in this way—we know how to take care of the chemical side of the proposition, but we are enormously hampered by the lack of cheap power. We hoped that you, electrical engineers, were going to help us in our needs. But when you talk so hesitatingly about the possibility of our water powers being cheapened, and, on the other hand, when we consider that our increasing steam power plants will exhaust so much the sooner our available supply of coal, I must say that I feel somewhat disappointed.

The situation is as follows: In some of our electrochemical industries, we are suffering from lack of abundant power even at high prices, say $20.00 a horse power year. The case has been very well stated by Mr. Lidbury. There are certain electrochemical industries where we can afford to pay relatively well for power, provided we get the power at the right locality, the right point for the market, the right point for freight, the right point for raw materials, and the right point for labor. Niagara Falls is one of those places, but the amount of power produced is all taken up, and further development is prohibited by law. Then there are some industries which could not live in Niagara Falls, even if you could supply them with all the power of Niagara Falls, because the price of power there is too expensive, and I cannot better illustrate this than by taking the example of our contemplated nitric acid supply in relation to the defenses of the country. When it comes to making nitric acid for war purposes, it does not matter how much it costs, because it then can be made regardless of cost. Nowadays the people who are fighting in Europe do not figure how much it costs them; someone else will have to pay for that. For example, phenol which in times of peace is rated expensive at seven cents a pound when it is to be used for peaceful industrial purposes was found cheap enough for the making of explosives in time of war at $1.75. The same thing can be said of nitric acid. The Germans, when they wanted nitric acid, did not discuss the question of the cost of power; they simply erected steam and gas power plants as fast as they could so as to become independent from Chile saltpeter in their nitric acid supply. But there is a more important question in connection with this subject, a subject of far-reaching national importance, and that is the production of cheap nitrogen-fertilizers. I am sorry to have to say that in connection with the production of cheap fertilizers, the problem looks much more difficult, because for this purpose, power should not cost more than five or six dollars per horse power year.

There is one point of view which has not been brought out

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here; our more expensive water powers in the United States, as compared to those of other countries, are mainly due to the fact that in this country there are always more contemplated enterprises looking for capital than there is money available. The business enterprises of the country are chronically short of money. They carry on so many enterprises and do this as quickly as possible, and this increases rates of interest; furthermore, our methods of banking are rather wasteful as compared with those of Europe. The result is that when we erect a water power the fixed charges which are incurred are much heavier than what they are in Europe for similar enterprises. Our rates of interest here are very high. In Europe people were glad to invest money at three per cent in various real estate enterprises, and in water power developments. In this country, by the time you float the bonds and give the usual rake-off to promoters, bankers and brokers, and after you consider a lot of side issues that are involved, your water power is already carrying fixed charges of $9 per horse power year, and this charge is fastened on the enterprise before you start to operate. This fact makes an enormous difference when we come to consider the cheapening of water power. Who is going to change this and how is it going to be changed, is a matter on which I cannot advise. Our bankers will have to use less wasteful methods and perhaps the Government may have to do its share by utilizing its excellent credit so as to obtain money at low rates of interest.

J. J. Carty: One of the purposes of this meeting was to call attention to the method of making the work of the bankers less wasteful—if that be a proper term to use—by establishing water powers upon a stable basis where the investor could know where he stood from one year to another. Money can be obtained in this country at low rates of interest or at high rates of interest, depending altogether on the certainty of return and the amount of return.

Owing to the obstructions which have been placed in one way and another about the development of water power, prudent investors and conservative bankers, whether they be located in Europe or in America, have found that only a high rate of interest would attract the people away from more stable investments into the vicissitudes of water power development. If I understand the character of these papers submitted today, and the general situation, the main object is to remove the uncertainties which entangling legislation has cast about the development of these water powers and then the bankers and investors will be in a position to reduce the cost of these hydroelectric powers by furnishing capital at a lowered rate of interest commensurate with the lowered risk, which would certainly ensue the moment that stability enters into the chaotic legislative condition.

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L. S. Randolph (by letter): Mr. Stillwell overlooks one or two points in regard to the locomotive situation, which I think should be dwelt upon.

The largest locomotives that we have been able to get only give about 4000 or 5000 h.p. and that seems to be the limit for the present length of locomotive.

Six drivers in series, or coupled by one set of rods have been used but were not found successful, five are being used on some of the Western roads where very heavy grades are concerned, but as a rule four drivers coupled together or the consolidation type, seems to be the limit and in the Mallet many of these are running back to three pairs of drivers coupled together, although the Henderson Mallet on the Erie has four pairs of drivers coupled together, having three sets, making twelve pairs. This seems to be the largest locomotive so far and the problem comes to " what is the limit in length?" as it is practically impossible to increase the cross sectional area of the locomotive, and therefore increase its size in that way. It is as high now as the bridges and tunnels will stand and as wide, and any increase in that direction would mean an entire rebuilding of the permanent way.

So far, the voltages now used permit 9000 h.p. and this has been transmitted by one wire, two wires, of course, would double this, and with higher voltage and smaller amperage still greater h.p. could be transmitted, and with motors under each car, as in the case of street railway cars the limit is almost infinite.

Another point that should be considered in figuring on the economy is that the coal consumption is really a comparatively insignificant item. If one studies the development of the steam locomotive he will find that for years and years, in fact, up to the last five or ten years comparatively little attention was paid to the coal consumption. This was due to the fact that the addition of one or more cars would add to the income of a railroad enormously greater amounts than the cost of the additional coal; so that all the development was towards increasing weight, size, lessen track resistance, etc., so as to get the highest possible hauling capacity for a locomotive. Some five or ten years ago the limit of the size of the locomotive was reached, and therefore the limit of the size of train it pulled. Attempts were made then, not to reduce the coal consumption so much, but to get a larger capacity out of the boiler and a larger h.p. capacity out of the coal consumption. We had from this, the introduction of super-heated steam and feed-water heaters, which were adopted not so much towards the saving of coal as for the increased capacity.

The application of electricity to steam railroads is indicated at the present day wherever the density of traffic makes it impracticable to handle readily the traffic with the steam locomotive, as a case in point, it is stated that on the Elkhorn Electrification of the Norfolk & Western Railroad in West Virginia, four or five electric locomotives handle the work that required seventeen Mallets of the largest type.

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Wherever such a state of affairs exists as just mentioned, electrification will give large returns on the investment.

Lawrence Addicks: I think we must all be struck in this discussion with the philosophic tendency which it has taken. It shows that the engineer of today has to be a political economist, a conclusion at which he has been too long in arriving.

As to Mr. Lidbury's discussion I think it is safe to say that power could be sold for $20 a horse power year from a large plant, meaning perhaps a 25,000 or 30,000 kw. plant, but I qualify that to this extent, that we assume the prices for fuel, labor, etc., that prevailed up to a short time ago, and not the high prices that are prevailing temporarily on account of the war situation.

As to what Mr. Stott said about the load factor, of course, a number of us in the electrochemical industry feel that we have a 100 per cent load factor, and the question does not enter there as in public utility work.

As to what Mr. Stillwell said about interruptions of service, my feeling is that it is not practicable to talk about diurnal interruptions, in order to decrease the consumption of power, of three or six hours a day—I do not believe it will work out satisfactorily, except in some possible case such as the carborundum industry, where the whole furnace is torn down after a certain number of hours run. I do think there is a possible solution, which seems a little fantastic. Suppose we took Niagara Falls and put the whole four million horse power in water wheels, and that it was agreed that the plant should be shut down every Sunday morning, for say six hours, so that we could turn the water back into the river. In this way you would satisfy everybody. You would satisfy the power people, because they would get the power which they require. You would satisfy the conservation man, because he would have the scenery, and he could see it once a week. It would satisfy the hotel man, because more people would come up to see the river turned back than came to see it running in full force.

Allerton S. Cushman: Mr. Addicks has referred to his impression that the gentlemen who have discussed these papers have treated them from a philosophical viewpoint. That has not been the impression made upon my mind by most of the discussions. It struck me that many of the engineers were principally interested as to whether water power or steam power would be the best paying investment under present load factor conditions. My own mind has been more exercised with the probable future needs and conditions of the country than with dividend prospects under present conditions. If it is true that we are to expect a population of two hundred million people in this country within the next half century or so, it is about time to begin to study the power requirements of the future and to discuss water power development from a somewhat broader viewpoint. For my part, if it requires for the time being a sub-

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sidiary steam plant to make a water power plant pay, I would rather have it that way than allow our water to continually run to waste. This may not sound very practical, but surely there is such a thing as building and preparing for the future. Moreover our electrochemical industries need water power, and already in some cases are going abroad to find it. I am at least practical enough to realize that if we are to have cheap water powers we must have cheap money to develop them. The government can borrow money at low rates, or the government could guarantee or endorse water power bonds under properly safe-guarded conditions. I for one can see no harm in such a suggestion, and would advocate such a plan if I had the opportunity. To my mind it is one way of keeping the government out of business, but I confess I would rather have our government develop those water powers that ought to be developed than not have them developed at all. The government might build the dams and lease the power under proper regulation, but this would mean the use of government money, with the usual pork barrel danger. Under a guarantee plan, the government would use nothing but its credit unless some water power failed to earn the interest on its bonds. Why should Norway get cheaper money than we for water power development? Some way out of this situation ought to be found, for many people in this country believe that these things are worth doing and worth doing now.

L. B. Stillwell: The last speaker, Dr. Cushman, made a statement which it seems to me is fairly debatable from an economic standpoint. To my mind the proposition that the government should endorse water power bonds is economically as unsound as—possibly it is worse than—the proposition that the government should build a system of canals to parallel our railway systems. The government never yet has been able, I think, to father industrial enterprises or transportation enterprises with that degree of scientific discrimination which is essential to a right result.

Private capital in this field needs no endorsement by the government. What it wants from the government is security of tenure—definite title or definite lease—so that it can at the start before making its investment estimate all the essential factors which it must know in order to justify investment.

Until we have evolved a very different system of economic administration of government in this country, I should be sorry, indeed, to see the government embark upon a plan of endorsing water power bonds.

I do not know that there have been any points in my paper which have been discussed that I need refer to. Our president has touched with great clearness and with emphasis upon the point made by Dr. Baekeland in regard to the high rate of interest. I believe that the high rate of interest which we have to figure when estimating a water power development would be

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materially reduced if we could secure a definite tenure and if we could feel sure that the going concern would not become an object of unjust attack through the power of taxation. It is the fact that these factors are today uncertain which in my experience frightens investors away from water power development.

The one thing that we need to do—we engineers and all of our citizens who understand the economic facts—is to educate the public and to assist our legislators to get the economic facts in proper perspective in order that we may secure legislation that will permit us to go ahead. It is nearly eight years now since the agitation began in regard to western water powers, and it would be hard to name a water power of importance that has been taken up and developed *de novo* during that time. There are a number of cases where plants have been extended, where a growing business and the fact that money was already invested compelled an extension, but the number of new ventures is not great.

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DISCUSSION ON "WATER POWER AND DEFENSE" (WHITNEY), "THE WATER POWER SITUATION, INCLUDING ITS FINANCIAL ASPECT" (DUNN), WASHINGTON, D. C., April 26, 1916. (See PROCEEDINGS FOR MAY, 1916)

(Subject to final revision for the Transactions.)

F. A. Lidbury: I am glad this question has been brought up, because there has been for years a tendency on the part of electrical engineers in connection with their valley load problems to assume that the electrochemical industries can offer an easy solution. The tendency appears in various ways. There is the steam central station man who comes to electrochemical manufacturers and says, "We can offer you lots of power at cheap rates if you will only take it for a few hours of the day." When you find out what he means by cheap rates you get a shock; but putting that aside, and putting aside the fact that few electrochemical processes can operate satisfactorily in an intermittent manner, let us see what he is trying to do. He is trying to relieve his prospective customer of the investment portion of the cost of the steam power. What is forgotten is that he is asking the customer to increase his own investment charges.

Putting all other considerations aside, let us see how that works out. The consensus of opinion as shown by the figures given today is that the cost of steam plants may be taken as something like $60 per kw. capacity. I venture to say—and I have consulted some of my electrochemical friends present who confirm the statement—that there is not an electrochemical plant in the country that does not involve an investment of at least $50 per kw. in plant cost. Many electrochemical plants run to several times that figure, and the average would be much higher, and might be two or three times as high. What the central station man is asking is therefore that his customer should increase his investment charges to an extent usually considerably greater than those of which he is being relieved. Intermittent operation is in some cases not possible, in others at least inconvenient; but the fundamental reason why these industries do not gobble up the off-peak of steam central stations is the one just given.

Then there is the question why electrochemical industries do not flock around those water powers which have valley power or secondary power at—in this case actually—relatively cheap rates. The answer is again that the added investment cost, taken in conjunction with disadvantages of intermittent operation, is such as to more than neutralize the advantage of the lower power rate. Partial time operation of electrochemical plants does not therefore offer much hope as a solution of these problems. I am not saying that there are not times when it can be done, but I am speaking now of normal conditions.

From the electrochemical point of view the figures given in Mr. Dunn's paper would require modification. His comparisons between the cost of power from steam and hydro-electric instal-

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lations, on the basis of a 50 per cent load factor, would be very different on the basis of a 100 per cent load factor. It is obvious from a consideration of the figures Mr. Stillwell gave this afternoon that water power costs become relatively more favorable than steam power costs as the load factor increases, and vice versa; and, as Mr. Stott pointed out this afternoon, there is under every set of conditions a point where the two curves cross. The load factor of electrochemical plants usually lies well above that point.

There is one corollary which is not usually drawn as clearly as it should be. Mr. Dunn mentioned some of the favorite legislative prescriptions put into bills in connection with water power. One of the most ridiculous of these, which occurs in almost every bill relating to water power, is a provision that preference in the distribution of such power shall be given to municipal and similar purposes. In other words, you must provide the type of power which is most costly to develop with those particular loads which have the worst load factor. It has been sufficiently pointed out today that for that kind of load, even under the most favorable water power conditions, a steam plant will do the work cheaper and better, and it is about time that we got it out of the heads of legislators that the proper, decent and reasonable thing to do is to tie a water power plant preferably to those loads of the worst possible load factor.

In connection with legislation one or two other points must be considered. There is the question of taxation of water power to which Mr. Dunn referred. It has been clearly pointed out, principally in Dr. Whitney's paper, that for certain electrochemical processes, particularly for the fixation of nitrogen, we have got to have power at much cheaper rates than at present in order to permit their development. Specific taxation of water power is not likely to lead in this direction; it simply makes it more difficult to introduce industries which the country vitally needs.

Next, as regards the provision that water power plants shall revert to the government, say at the end of 50 years. What about the consumptive industries that have sprung up around such water powers? In most cases where artificial restraints are not put upon distribution, these will largely be electrochemical plants. These plants will be useless except in connection with the water power plants, and they will be providing supplies of fundamental importance to the general industries of the country. The investment involved in these electrochemical plants will be at least as great as, probably considerably greater than the investment involved in the water power plant itself. That is a matter which should receive very careful consideration—what is going to happen to these plants, to the investment they represent, and to the industries which have become dependent on their products, if by some carelessly drawn reversion clause they are liable to be thrown on the scrap heap at the end of 50 years?

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Most of these points are more or less related to the strictly electrochemical side of the question; but I feel very strongly that either the future of most of the water powers in this country will be bound up with electrochemical industries, or there will be no future at all for them.

Lawrence Addicks: What Mr. Dunn says about seasonal variation puts a little different color on this question of off-peak power. I have been thinking of diurnal variation, and I think Mr. Lidbury was in what he said, as I certainly was in connection with what I said this afternoon. If you put to us the proposition what we shall do in the ten months of the year, our first question is—what do you mean by cheap power? Do you mean $10 per h.p. year or anywhere near that figure?

Gano Dunn: That or better.

Lawrence Addicks: What will we do with large quantities of power at $10 per h.p. per year, ten months a year, and nothing for the rest of the time? That requires a business which could be carried on by using the current for a part of the time, and working up the product in other ways the rest of the time, and in the few minutes I have had to consider the matter, I can not think of any case where it looks inviting. In order to comply with the proposition it means that we must use so much power in the business that the cost of the power is the main thing, and we will do anything to get cheap power and shut down the business for two months in the year, during that time paying fixed expenses and salaries.

One of the industries in which such a proposition might be considered is the nitrogen industry by the arc process, and I think it would be a very interesting thing to consider. We are now trying to get the government to consider this manufacture of nitric acid from the air, and we are talking of subsidizing the industry, and if Mr. Dunn will come forward with a proposition which will yield very cheap power ten months in the year, it would be worth considering. The arc process uses about 25,000 kw. per ton of 100 per cent nitric acid. The aluminum industry is another which might be considered in this connection.

John H. Finney: The answer to Mr. Addick's question in connection with the aluminum business is perhaps best found in the fact that we are building today something over 150,000 h.p. in hydroelectric power for the manufacture of aluminum, to work twenty-four hours a day, and 365 days in a year. I do not believe secondary power, even for ten months, would interest an organization such as ours.

I should like to comment briefly on Mr. Dunn's paper. The electrical engineer is essentially an optimist. That may not be apparent from the papers read today, and from some of the discussions, but if he were not an optimist, I do not think he would be found here today talking water power. If he were not an optimist, he would be, by this time, thoroughly discouraged by the stagnation that has existed for the last eight or ten years in

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the water power business. If he were not an optimist he would not still be trying to "unlock" as President Wilson puts it, this great natural resource and this tremendous, though latent, asset towards industrial advancement and preparedness.

The purpose of the meeting of the American Institute of Electrical Engineers and of its Water Power Committee here today was to call attention to a phase of hydroelectric development that seemingly has not had much thought by legislators and department officials who deal with this question.

We thought it might be helpful to stress the important uses to which water power can be put by the electrochemical and similar industries. Congress has in mind the value of water power measured by its public utility use solely, and the vast majority of the water powers of the United States are not in that class and never will be, in my opinion.

The great bulk of the water power in the United States is only available for what might be termed a semi-public use—a so-called private use, it might be, of the electrochemical industries, the semi-public use of power for pumping water on to arid lands; serving as motive power in the electrification of steam railroads; in making fertilizers, or in making nitrates for explosives. These are not, strictly speaking, public utility uses, but are much broader, much more important, in that the energy creates not incandescent lighting for instance, but the vastly more valuable products embraced in increased transportation, or increased agricultural production or new and cheapened products of the electric furnace or electric bath.

The public utility use of water power is mainly that of using it as a part of the combined water and steam generating system and therefore it might be no particular hardship to the public service company to have a given water power taken away from it at the end of a fifty year period, because they could at that time substitute a steam plant, or perhaps another water power plant if it were in reaching distance of their operations, but the great mass of these chemical operations, this irrigation work, this electrification of steam railways, requires, first, *cheap* power and secondly and just as importantly, it requires *permanent* power. These operations require power in perpetuity, and that is another thing that our Congressional friends do not seem to have in mind, *viz.* the difference between permanent use, and permanent rights. Great works of the expensive and permanent character required for the development of water power cannot be financed with the expectation or suggestion that they must be abandoned at the end of a fifty year period, or that money invested in them is subject to suspicion and to grave risk of confiscation in whole or in part.

Permanent works are built to supply a permanent use which so far as we can now see will always be performed in the same way—whether the original lessee continues to perform it or another lessee or the Government finally performs it, does

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not greatly matter, it seems to me, so long as it is proposed to deal fairly and equitably with the original lessee. Cheap water power in the United States is only possible with cheap money to build water power plants—every unnecessary property restriction causes dear money and more costly power, and materially limits the available water power resources of the nation, as has been well pointed out by Mr. Dunn and others.

If the Institute can bring about a better understanding of what these industries mean in their importance to the nation, we have felt that we would be doing ourselves credit as leaders in the electrical arts, and we would be doing the nation a service, by pointing out what we consider fundamental engineering principles and fundamental economic principles, without the recognition of which no permanent water power policy can be written by the Congress that will bring about that wide development so necessary to the industrial growth of the nation.

L. H. Baekeland: Mr. Gano Dunn referred to some statements I made this afternoon on the subject of wasteful banking. I would like to explain what I meant. Before doing so, I want to answer the remark Mr. Finney just made. He asked: "What is the real importance of some of these electrochemical industries? I could take, for instance, the manufacture of nitrogen-fertilizer which requires such very cheap power, and for which the market is almost unlimited if it can be supplied at a sufficiently low cost. In all our discussions we have been rather indefinite as to what we mean by cheap power. For instance, in the city of Yonkers, I am charged 12 cents a kilowatt hour for current. I think that is cheap, because I cannot do any better, and furthermore, the matter of annual expense in this case amounts to little. So I do not mind much the 12 cents a kilowatt hour they are charging me. I am kicking more about the ugly poles with which they are butchering the landscape and defacing my property, and I would gladly pay 15 cents per kilowatt hour and call it cheap if the company did not put its horrible poles in such inappropriate places.

But when we speak of cheap power for fertilizers we mean $4 or $5 per horse power-year, twenty-four hours a day continuous service. Why do we want cheap fertilizers in the United States? I was born in a country where farm labor is unusually inexpensive, and I know, therefore, that there is hardly any comparison possible between cost of farm labor in Flanders and that in the United States. In Flanders, farm labor is mostly a family affair. The peasant, his wife and children work in the fields, and they feel happy in doing so. They receive no wages; they work practically for their board, and even that does not amount to much.

When farmers, at such low rates of labor, find it profitable to utilize cheap nitrogen fertilizers—and after all fertilizer is a labor-saving device—when we see again that in this country, where farm labor is incomparably more expensive, we cannot

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afford to use cheap nitrogen fertilizer, because it costs twice as much as in Belgium or Germany, then " there is something rotten in the State of Denmark."

We can produce very cheap nitrogen fertilizer by fixing the nitrogen from the air if we have cheap power. The chemical processes to do this are well known and the sources of cheap power are here too. But for several reasons, by the time we develop the power, it has become too expensive for profitable use with these processes. Some of these reasons have been well put forth by Mr. Gano Dunn, and what I am telling you now is not in opposition to his statements. Right here is where our wasteful banking comes into play.

When twenty-seven years ago, I landed in this country, one of the first things which struck me was that most commodities here are cheap enough at their source of production, but they are tremendously more expensive by the time they reach the consumer. If I were to put it in another way, I would say that one of the curses of this country is the unnecessary multiplication of middlemen, and this situation goes against the grain of engineers or chemists who work for efficiency. Sometimes I think we are a lot of fools when we work and put forth our best skill, our best efforts, striving to increase efficiency in power production or in chemical processes so as to decrease the cost one cent, or a fraction of a cent, or to reduce power consumption a few per cent and then, after we are all through with our improvements, our increased efficiency looks like a mere trifle if we compare it with the big gap of waste which has to be bridged between the producer and the consumer.

Now in regard to water powers: Take, for instance, a suitable water-power site, including real estate and water rights. An engineer comes along and sees the possibilities of the situation for water power development. Almost immediately he is confronted with some real estate speculation in which some men have to get rich. The next step is the advent of the promoter who wants to get rich too, and most of the time very quickly. Then comes the banker and the bond-broker, and then finally the water power enterprise gets to the point where the equipment gets into the hands of a manager, and the power is now available to the consumer, who finally finds that it is too expensive for him to use it, because at each step in its development, the fixed charges have been increasing. That will not do for cheap power. Cheap powers in Norway, or other places abroad, are not burdened by those extraordinary fixed charges which were incurred by having to go through all these middlemen. Whenever one set of financiers or underwriters control the whole enterprise from the inception of the water power to the construction of the chemical works and the delivery of the final manufactured product to the consumer, it stands to reason that the final cost of the water power will be cheaper. In some cases here in the United States, I found that the cost of operating water power

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represents only 10 per cent of the fixed charges introduced by banking or financing, so that any important reduction of the cost has to be found more in the financial end than in the engineering or operating part of the proposition.

Now, what would you say, for instance, if you started to manufacture sulphuric acid, and if first of all your plant is located on a piece of leased ground where you are compelled to pay such an exorbitant rent because the people who possess the real estate have to get rich by it, and then when you purchase your raw materials, another set of people have to levy considerable profit on this, while you, as a manufacturer, would have to get your share in the manufacturing operations after being confronted then again with a selling agency which would claim high commissions, until finally the product, after getting through the hands of all those middlemen, comes in the hands of the consumer at a greatly increased cost. The up-to-date sulphuric acid manufacturer, in order to make a success of his enterprise, begins by owning land or real estate, and he secures his raw materials directly, and when it comes to selling, he does not have to go through the additional expense of middlemen. Therefore, he can afford to deliver his sulphuric acid at a minimum cost. Somehow, we have not yet reached that point in the utilization of our water powers. It is true that in some cases, none of the intermediaries get very much separately, but in the end, they all get something, and these expenses are multiplied collectively until they sum up to a considerable increase in the cost of power, and that is the reason why our water powers are generally so much more expensive than they are in some other countries.

The remarks of Mr. Dunn are correct, that our capricious and ill-digested methods of legislation on the subject of water powers have not contributed to make enterprises of the kind more inviting, and this has raised the rates of interest at which money could be borrowed for this class of enterprise.

On the other hand, we are told that in Germany or some other European countries, there is no opposition between private enterprises and the government, such as has existed of late in this country. I should point out that this matter was disposed of by the very fact that in many instances, the German government has run these public service enterprises as a monopoly or has become a partner in them. For instance, there is no struggle between railroad companies in Germany and the German government for the reason that the German government owns and runs the railroads.

A short time ago, in studying the taxation system of Germany, I found that the earnings of the government railroads paid about 40 per cent of the total expenditures of the German government, and the general taxes of the country are reduced by this amount. In other cases of public service enterprises, like mines, etc., the government became an important partner in the enter-

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prise, and in this way, succeeded in controlling easily these enterprises from within, instead of trying to curb them by drastic legislation from without.

I do not say that we should copy these methods. I merely want to point out where we are laboring under difficulties which might be removed if some way could be devised by which the government could enter into efficient cooperation with these enterprises. Some of the privately owned public enterprises in this country, I am sorry to say, have not always been carried out in the interest of the stockholders who had invested their money in these properties, and this too is a very important reason why capital has become shy and wants increased interest rates so as to make up for any contingencies of failure aside from fear of disturbing legislation. This undoubtedly has raised the fixed interest charges for any similar enterprises which might have to be launched.

In England, canals which once were privately owned, were subsequently bought up by railroads and they proceeded to take great care that the canals could not be used in competition with the privately owned railroad enterprises. In this country, we have become so "socialistic" as to have canals which belong to the state. I understand that in Germany, all the canals are owned by the government, and I know that they are kept in the most splendid condition of efficiency and the government can afford to maintain and improve them even if such action is in direct competition to the operation of its own railroads.

In general, there is a great difference in efficiency in any country when enterprises or the details of government are run by engineers and experts instead of by politicians.

Mr. Gano Dunn, a year ago, in this city of Washington, advanced the idea that an engineer should never mix in matters of government administration. I told him at that time, that I disagreed with him. Then after his interesting paper today, I disagree still more, because he has proved by his own example the versatility of our engineers.

We are encountering quite some difficulty in the problems of government of this nation. But we should not be too impatient. These matters are straightening themselves steadily—only a pessimist can deny this. We are confronted in this country with entirely new problems which have to be treated in new ways. These problems are considerably complicated by the immense and rapid growth of our Republic. The fact is that this country, as it grows larger and larger cannot keep on being run in the easy-going ways of a mining camp. We have come to a point where we have to change our methods, and in this we have to do some experimenting, just as we are doing in our chemical industries. If it were not for direct experimenting, our chemical industries could never have made progress. We are very lucky if, only once in awhile, some of those experiments are successful, and we do not count so much the ones which have been unsuc-

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cessful as long as we make headway. These problems cannot be solved by a general formula, inflexible and everlasting. Furthermore, whenever we discuss these problems, we are apt to be carried away by one single point of view or another and on this account, we frequently exaggerate one single feature by looking at it from one standpoint. This is the mistake of most of our politicians. When we talk about these matters, let us discuss them like engineers. Let us use quantitative argumentation and let us impress those of our friends in Congress or the Senate who are really willing to learn that we, at least, can look at the situation with a due sense of proportion by using quantitative arguments and not be overawed by merely qualitative considerations.

C. G. Atwater: The point I want to discuss is contained in the first sentence of the summary in Mr. Whitney's paper, namely, that the United States has no adequate source of fixed nitrogen. I think that point is open to some question. Further along the paper makes an exception of the gas and coke industry.

I presume that Mr. Whitney in writing the paper did not consider the dimensions of these industries nor the present conditions that prevail in them. As a matter of fact, so far from there being no source of fixed nitrogen, there is being produced every year in this country from the carbonization of coal to make coke about 750,000 tons of sulphate of ammonia, or equivalent to that. That figures up pretty nearly to our whole consumption of fixed nitrogen. It is not all being recovered, but it is a source known to be open for the recovery of that amount. There is at present being recovered of that amount about 220,000 tons of sulphate of ammonia per year.

That is a very fair proportion, but it is being largely increased. The development of the coking industry that has come with the present abnormal conditions, though largely from the natural growth of the iron and steel business, has brought about very nearly the doubling of that industry, potentially, within the last few months; that is to say, contracts have been let for some 2600 coking ovens which will produce about 150,000 tons of sulphate of ammonia per year.

Now, as you will see, that is very far from the country being in a position of having no adequate source of fixed nitrogen.

I do not wish to make these suggestions from the point of view of checking or discouraging water power development, but when you come to figure these things out and deal with our friends the bankers and others, these points will have to be considered.

There is a tremendous increase under way in the by-product coke ovens, as I have said, and it will amount to more than I have stated, because I have only referred to ovens actually under contract. There are 2000 or 3000 more under consideration. The business of recovering the by-products wasted in

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coal is being rapidly developed to somewhere near the position which it should occupy. That is also being applied to the recovery of nitric acid. It will be possible to convert ammonia from coke ovens into nitric acid. There is no question also that the development of the coke ovens will contribute toluol and other substances essential in time of war.

Calvert Townley: I had an opportunity some fifteen months ago of visiting the nitrate pampas of Chile and of inspecting the methods used for getting out this valuable product. It may interest you if I say, that I was impressed with the possibility of very greatly cheapening that product to the ultimate consumer.

We must remember that for a long term of years the Chilean nitrates practically had a monopoly, that is to say, the output of Chilean nitrates so largely exceeded that of any other similar products that the competition of such products was unimportant. The nitrate earth of Chile was very rich and to work it was very profitable, no matter how inefficient might be the methods of extracting the nitrate, consequently the processes were crude in many respects, and the operators did not seek for the economomies which might have been practised if the pressure of competition had been severe. I am not a chemist but it was apparent even to me, as it would have been to any engineer, that there were possibilities of material improvement in the economy of the production of nitrate.

When I was there, owing to the European war the industry was prostrate. Only about 30 per cent of the plants in the country were in operation, and these were running on part time only. Some 30,000 laborers had been thrown out of employment, and I never saw a more discouraged and disheartened set of men than the operating officials who had to do with this industry. They did not know what was going to happen next. One thing which had happened was that they were studying to improve processes for the extraction of nitrate, and it is usually a safe prediction that when a body of men who have been interested in an industry for a long time have sufficient incentive to make improvements they will make them provided there is any considerable margin to work on.

Before the war the Chilean government received some 60 per cent of its annual revenues from export duty on this nitrate which amounted, in round figures, to about $11 a ton. It is an arbitrary duty which of course can be changed, and because the industry was then almost prostrate the question of modifying this duty was being discussed. If artificial processes for getting fixed nitrogen should be established on a scale large enough to jeopardize the Chilean industry it is only a fair prediction that the Chilean government will reduce its export duty.

There is still a third direction from which a reduction in the cost of nitrate may come. The cost of transportation—bringing

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the Chilean nitrates from the pampas where are the mines and reduction mills to the American market, has been abnormally high. None of the reasons for this fact are fundamental; they are all more or less the result of monopoly or of limited facilities and the cost is consequently subject to future reduction should the transportation agencies be improved or competition become severe.

The very live possibility that our country may become involved in war and the pressing need of providing for such a contingency should not blind us to the fact that we have lived many years at peace with the world and are likely to so continue —therefore no plan for producing nitrogen will be economically sound which is not commercially practicable under peace conditions. While the quantity of nitrate in Chile has been seriously depleted it is still sufficient to supply the world for years to come and its early exhaustion can therefore by no means be counted upon. This means that any cost for power which we may now estimate to be low enough to permit the artificial fixation of nitrogen in competition with the natural salts, may have to be radically revised downward later on. That furnishes another reason why we must make every possible effort to cut down our power costs. On the other hand, of course all of the processes for the fixation of nitrogen as now known are relatively new and susceptible of much improvement. I understand that not more than 15 or 20 per cent of the electrical energy required by the arc process is actually used in the fixation of nitrogen. Perhaps some of my chemical friends will correct me if I am wrong.

L. H. Baekeland: It is 2.5 per cent.

Calvert Townley: Well, it is worse than I thought it was. That being the case, is it not fair to assume that with the brilliant minds which are at work on this problem a great improvement is likely to result? May we not hope that the processes will be so improved that the industry can prosper with very much greater power costs? A process with an efficiency of 2.5 per cent which could live and pay $7.50 per h.p. per year could presumably do quite as well with a $22.50 h.p. if the efficiency could be raised to 7.5 per cent. One way to have the processes improved is to get people into the business. We all know that there is no teacher like experience, that necessity is the mother of invention, and that if we can get not one, but a dozen, or fifteen, or twenty, or even a hundred corporations interested and competing with the hope of ultimate profit, such competition will bring out the best efforts of the brightest minds. The result will be that in this industry, as it has been in every other industry with which electricity has been connected, the efficiency will rise and costs will go down, making it possible to use power at a cost which now is entirely out of the question.

Those are to my mind important reasons why we should set ourselves earnestly to the task of getting this industry on a basis where it can go ahead.

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One thing very clearly shown in Mr. Dunn's paper, is how large a part the cost of capital plays in a hydroelectric enterprise. No engineer could fulfill his obligation to his client without considering the question of the security of any investment. Technical matters can occupy but an insignificant and minor position if there is a risk that the entire sum put into an enterprise, or any part of it, may be forfeited.

Capital conveys to many minds quite an erroneous notion. We are apt to think of it as something entirely separate and apart from ourselves. We think of a banker as a man who himself puts his own money into enterprises. Now that assumption is fundamentally wrong. Investors are not the bankers they are the men in this room. They are all of us, and our friends. To be sure we do not individually build water or steam power plants for the very obvious reason that such enterprises require large sums of money and there must be some one who will undertake to find out whether or not an enterprise is right and sound and then get the necessary funds together for the undertaking. That is just what the banker does. He is a sort of Captain of Money. He scrutinizes an enterprise and agrees to or refuses to back it, not because he himself likes it, or because he does not like it but because he knows the sort of investments which his clients, you and I and our friends, are likely to put money into.

Some one said something here this afternoon rather critically about the lack of patriotism in capital. Now, capital is a commodity just like grain, or cattle or clothing. It can be obtained for a price and it goes where it can find the best market. Not one of us would stand silent, accused of lack of patriotism, but who is there here who would put his own savings into an unprofitable or an unsafe enterprise to help develop water powers in the west when he might invest it profitably somewhere else? To rail at the man with money because he will not let us have it at a lower rate than he can get elsewhere is just as unreasonable as to demand that our grocer sell us eggs at 30 cents per dozen when he can get 40 cents from every one else in the neighborhood.

As Mr. Dunn remarked, capital is an international fluid. It flows into channels of least resistance. The price of capital is affected by the same laws of supply and demand that govern the prices of every other commodity. If it is higher in this country than in some other country for any individual class of enterprises it is because that class of enterprises lacks some feature of fundamental value. In Mr. Dunn's comparison of the operating costs of typical steam and water plants the capital rental for steam is 19 per cent as against 77.4 per cent for water. If by creating public confidence in the stability of investment and otherwise making these projects financially attractive the rate could be reduced say from 7 per cent to 5 per cent the annual cost of a steam unit of power would come down 5.4 per cent and that of the water unit 22 per cent.

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One thing capital looks for is earning capacity, and another thing is stability. Nearly all enterprises can get capital at some price because there is an abundance of it; but when any project lacks certainty of ample earning power on the one hand or stability on the other, that fact will be reflected at once in the price of capital which will demand a higher return.

One thing America can do to reduce the rent of the capital which water powers need is to remove all the unnecessary handicaps with which it is now loaded One of these is the lack of stability. Warned by the losses suffered in the past by many water power investors, cautious people now hesitate to incur similar risks; consequently, the source of capital supply is restricted to that extent and a higher rental prevails. If we can eliminate this disability capital rental will fall and the development of the water powers throughout the entire length and breadth of the land will be stimulated.

One speaker referred to the lower price of money abroad He mentioned the paternalism of Germany in handling their railroads and other enterprises, and by inference at least drew a comparison unfavorable to American bankers and their supposed unreasonable demands. As far as my information goes there is no more ruthless financier than this same German banker. He is certainly no more keen to lend his money to an unprofitable enterprise, or at a lower rate of interest, on account of patriotism, than the American or English or any other banker. During my tour in South America, I learned about some methods of the German bankers doing business in those countries. I found that they exacted rates of interest which even the most rapacious American banker would not think of asking at home. They did it for just one reason, local conditions justified the rate and they charged the market price for their money. They could get it and they are going to continue to get it. You can rest assured that when a foreign banker lends his money to hydroelectric enterprises in his country at lower rates of interest than the American banker does in the United States, it is because the foreign investment is more secure, because experience shows that the foreign government is going to protect that investment and the risk of loss is correspondingly reduced.

This afternoon Mr. Stott spoke about the low cost of power from steam and the increasing severity of the cost competition with which water powers had to contend. The more I study water powers the greater respect I have for steam and if water power is to prevail at all, we must do our utmost to bring its cost down to the lowest possible limit. If steam can get down lower, steam will be used and water power will not be developed. But every time the cost of water power comes down a little bit its use is broadened and a certain number of water powers which otherwise could not be commercially developed are worthy of consideration.

That is the task to which I think we should address ourselves.

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The erroneous and misleading impression that has so long prevailed in the minds of many people throughout the land who have not studied the problem carefully and which has been reflected in the views of our Congressmen, that water powers are very cheap and enormously profitable, is being gradually dissipated and the facts are becoming known. Congress needs only to learn the facts to act upon them in an effective and patriotic way with the same singleness of purpose with which we would apply ourselves to an enterprise for a client. But the feeling that water power development is abnormally profitable to the promotor is deep rooted and of long standing. It still prevails in many quarters. Some Congressmen believe that the interests of the public are in some way different from or antagonistic to those of the investor and that it is their duty to safeguard the people's cause by driving a bargain, so to speak, with capital and by trying to see how little they can do to induce investors to put their money into hydroelectric enterprises. It would be unfortunate if the government which is seeking to have its resources developed by private enterprise without contributing its credit or assuming any risks whatever should adopt a policy which will just not accomplish the desired result by reason of over zeal in attempting to drive a bargain with the investor who is in no way whatever obligated to supply funds for such enterprises.

George R. Smith: Since going to Congress I have given this subject consideration from the view point of the public as well as the investor. I take it, from what I have heard tonight, we do not all look at it from the view point of the capitalist, the man who invests his money. Now, I agree with you that there should be certainty of tenure, and there should be certainty of a reasonable return on the investment. I would say, in view of what little I have done in the way of helping along legislation that if the members of this Institute are ashamed of the sort of legislation which is before Congress for its consideration, as is indicated by statements made, that they have another guess coming, that there is nothing quite so bad as some of the remarks would indicate.

Ever since the veto of the James River Bill we have been trying to get legislation through Congress that would protect the public and at the same time protect the investor, and up to the present time we are just as far away from that as we were when we started. I think that the Shields Bill is no better, possibly no worse than previous bills that have been introduced on the subject.

I want to leave this thought with you. Mr. Dunn put his finger on the sore spot when he said that public utilities could be regulated by commissions,—but he failed to say what kind of commissions. Mr. Hugh L. Cooper appeared a little over a year ago before a committee of the House of Representatives, having under consideration the Adamson Water Power Bill,

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which is similar to the Shields Bill and stated that he was afraid of state legislators and state legislatures because he had seen so many awful things committed by them but had absolute confidence in members of Congress and, therefore, was in favor of Congress enacting a law that would authorize the Secretary of War to regulate the price and service of hydroelectric energy.

A few weeks ago in an article in the *Outlook*, when the Shields Bill was under consideration in the Senate, Mr. Cooper said that public utility commissions created by state legislatures will afford all the protection that is necessary for the public and favored state regulation of hydroelectric companies. I wish Mr. Cooper could understand when he appears before Congress at a time when we are seriously considering a piece of legislation which is so necessary as a thoroughgoing water power bill and makes a statement along one line and then in a short time afterwards makes a statement in the press diametrically opposed to the one he made before Congress, that he cannot be expected to be taken seriously. We understand that Mr. Cooper has shifted his position but we are not quite so clear as to his motive.

There is a great deal of suspicion abroad concerning the motives of representatives of capital who are advocating water power legislation; some of it is unfounded and some of it has a good foundation, a very good foundation. Now, going back to the matter that I wish to call your attention to, I will say that you have got to permit hydroelectric plants to combine in order to operate them economically. Every man who knows anything about the subject at all knows that that is one of the fundamental principles of economy in dealing with hydroelectric plants. In some cases a number of these plants have combined, a very considerable number, and the moment plants located in different states are combined, state utility commissions cannot regulate them because the current becomes interstate.

In Minnesota we are about to receive power from Wisconsin where there is a large power plant supplying power to various projects. At the present time, Minneapolis, gets its current from Taylor Falls on the state boundary line between Minnesota and Wisconsin. How can a Minnesota Commission regulate current generated in Wisconsin and brought into our state? How can it tell what is a fair rate under that situation? How can it inspect the books of a plant located in Wisconsin, which sells power to the Consumers' Power Company located in Minnesota? The Minnesota Commission has jurisdiction as to how much the Consumers' Power Company, which is nothing more or less than a distributing company, pays for its current but it has no way of determining whether the price paid by the Consumer's Power Company to the Wisconsin company is a fair and reasonable charge, and, therefore, is unable to determine what would be a fair and just rate to patrons of the Consumers' Power Company.

Nothing short of a Federal Commission authorized to work in

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conjunction with state commission will meet the situation which I have called attention to. Besides, under a Federal Commission, the work now being done by the Secretary of War, the Secretary of Interior and the Secretary of Agriculture, could be brought under a single head thus effecting a great saving to the government and assuring efficient regulation which would rebound to the benefit of the investor and the consumer.

The moment that the promoters, the investers, the engineers and the associations that are giving their time to this subject come to Congress with a fair proposition, fair to the public and fair to the investor, Congress will join hands with them in working out an efficient law. Congress is looking for light, it is looking for information. Members of Congress are also anxious to know why they are persecuted for daring to offer any objection to impending legislation that is offered by what is known as the water power monopoly.

Why, we know and you know better than I do, that the water power interests of this country are controlled by a very few men, the whole policy is dictated by a very few men. Mr. J. P. Morgan of New York City is one of the leading factors, and the General Electric Companies is the great big institution, with its subsidiaries, that controls the situation. I do not object to the monopoly because the development of hydroelectric power economically is a natural monopoly. The thing I object to is the refusal on the part of those owning the monopoly to admit that there is a monopoly and I object to their attempt to deceive the public as to the existence of such a monopoly, in order to defeat legislation having for its purpose the control and regulation of such a monopoly.

Mr. Cooper says in his article in *The Outlook*, that it is not a monopoly—he laughs at the idea, he scoffs at it— and yet we know it is a monopoly. Why do the water power interests try to deceive the public? What can be their purpose? Under such a condition of affairs is it surprising that members of Congress as well as the public, look with suspicion upon any suggestion coming from owners of this monopoly. But as long as the water power interest suppress the facts concerning the monopolistic tendencies of hydroelectric development, Congress of the United States cannot be blamed for its refusal to be rushed off its feet in the consideration of water power legislation.

D. B. Rushmore: I need not say that I came here absolutely as an individual. I came here in my capacity as a member of the Institute, and as a man who has spent his life on water power developments, and I will be frank with some of my experiences. I have never lost money to any extent in anything else except water power development. I have had a gentleman in New York tell me that he has had in one autumn sixty-six men who controlled water powers locally and also men from different countries come to him and ask him to help them to raise money for those water power enterprises. Now, there is

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one waterpower, not very far from New York, in which the man who controlled it for years was a friend of a friend of mine. This friend happened to call at our office, and he was turned over to me. He had the right to a waterpower and wanted to raise money to finance it, but could not do it. He had been working on it for years and no one would take it up. I had a friend of mine look it up and he said it was no good, that it would not pay, that it did not have a market. The proposition was finally taken to Chicago to people who were somewhat familiar with it. I know they had a difficult time raising the money, people did not want to go into it, they said it did not look good to them. The only place they could go to raise the money was to bankers familiar with the project. In my experience as an engineer I have always seen the pressure come from the other side. I presume there are in New York every year hundreds of men who control complete situations trying to raise the money for them. If you talk to a man who does not know anything about a waterpower, he will not listen to you. It seems to me there has been a great misconception about this matter.

Mr. Dunn has dealt with bankers and knows the difficulties of raising money and in my opinion his paper will add very much to the beneficial result of our meeting here. Mr. Townley's discussion can also be brought to the attention of those who are in any way interested in this very broad and important subject. The financing of water powers, as Mr. Townley said, very truly, is dependent on us. Would any of us invest our money in them. I know a couple of bond brokers who sell bonds in the Mohawk Valley. They go into Amsterdam and offer to sell farmers public utility and waterpower bonds, and what the farmers pay for the bonds depends on the conditions on which the waterpower can be installed and operated. The banker goes around and gathers up various opinions and finds out what the people will take the bonds for.

The time is here for a new era of publicity. We are all afraid of the things we do not know—what is behind the doors and what is not brought out is always largely open to suspicion. Take the public into your confidence, work with the public, put the cards right down on the table before the public and show them just what you have.

Oscar T. Crosby: The political problems confronting us in the development of our water powers are these:

First, to what extent shall the authority of the general government, as distinguished from that of the several states, determine the location, physical construction and physical operation of water power plants?

Second, what authority shall control the financial operations of water power companies, including in this phase the control of rates?

Third, assuming these two questions as settled in one way or another, what principle should underlie the control of rates,

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of financial organization, of return to capital and of possible acquisition by public authority of private property involved in water power developments? Let us take up these questions in the order I have indicated.

Navigable streams are now fully recognized as being under the jurisdiction of the general government. There is no contention as to the right of that government to determine for or against the placing in such streams of any obstructions whatever. There is very grave contention as to the conditions which may be constitutionally attached, or which in wise policy should be attacked, to a permission given by the general government in any particular case. Should the sole interest of navigation be consulted, with no consideration affecting investment except that the proposed works should not result in navigation costs greater than those which otherwise would fall upon the public?

Should consideration of flood effects, as distinguished from navigation effects, also enter? Should questions of injury and advantage to agricultural lands, through drainage or irrigation be considered by the United States authorities?

In raising these questions, we raise a series of constitutional issues which it would be long and hard to settle. Happily, they need not be settled. If Smith and Jones have overlapping and tangled rights in respect to a tract of land, and if Brown wishes to use the land, then, without waiting for the law's delay the proposed use of the land may be effected by a joint grant, or by parallel grants from Smith and Jones to Brown. Let Smith be Uncle Sam, let Jones be the State of Ohio, and let Brown be a water power company, and we may proceed to determine the physical questions surrounding any situation in a navigable stream. We may even go further, and thus cover the difficulties as presented by the question as to what *is* a navigable stream, according to the Constitution. The existing legal definitions are such as would let almost any creek into the dignified company of streams, which must recognize in Uncle Sam their overlord.

In my early years, as a young officer of engineers, I examined a "navigable stream (?)" in a buggy. Rubber boots would have done as well, but for the length of the thing.

However extreme the case, we may rest assured that a handsome appropriation will settle most "state's rights" doubts as to the navigability question. But if no appropriation be involved a real issue, affecting validity of permits, remains to be solved. Co-operation of Smith and Jones is the true, practical solution of this, and of the other doubtful points concerning floods, drainage, etc.

But the United States appears in quite a different role than that of overlord and largess-giver, when we regard the public domain in our Western States. Are we dealing here with a sovereign, or with a mere landlord-proprietor, subject to the laws of the local sovereign—the state? In my judgment, that is the true view of the case. But it is a much contested point.

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As a citizen of the United States, concerned that all states, east and west, should be in the same relation to lands within their bounds, I should be loath to see any assumption of an *imperium in imperio*, by the general government, because it holds as trustee certain lands in certain Western States. As one easterner, I want to register my cession of title in these lands to the people of the states within which they live. But if this battle cannot be won, then it may at least be compromised by the same principle of co-operation in grants that has just been proposed in the case of navigable streams. But this compromise should go no further than is required for determining the physical elements,—the construction elements—of each case.

When we meet the matter of financial control in all its aspects, I am firmly convinced that the states alone should determine. Even if the courts should decide that the general government has a right to enter this field, yet would I contend that as a matter of policy it should not enter it.

There are good men in the Washington bureaucracy, but there are few efficient bureaucracies in all the world. Can men be established in this city to administer wisely through subordinates the distant affairs of a Californian hydroelectric company? Will it be a bearable burden if an operator in Oregon must communicate with Washington in all those intimate ways which have been made familiar to us by the Public Utility Commissions of our states? Is the burden not now heavy enough when recourse must be had in so many matters to boards sitting in state capitols? And shall we have in the same state one control for steam plant generation, and another for water generation of electricity? What confusion! What discouragement!

Let us hope that this madness of centralization of control in Washington will pass.

Let us now consider the *principles* of control, without respect to the question as to which of our dual sovereignties is to exercise that control.

Men invest money in public utilities, not in order to charge particular rates for service, but in an effort to earn a return on the capital invested. That is the objective. A just and reasonable rate is a rate that will cause money and energy to flow into the enterprise which performs a given service, whether that service be the sale of electric energy or the sale of bread or shoes.

Then since it is right that there should be control of monopolies and since public utilities are necessarily monopolies (in the long run and respect to at least some part of their clientele), let this control express itself in contracts relating in plain terms and in specific figures the return on capital. Rates may then be left to those who conduct the operations, subject, of course, to the usual common law rule against discriminatory practises.

These contracts as to return on capital may vary very widely from case to case; they should generally be on a sliding scale basis, providing lower returns in proportion to assured success,

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but they should be specific and clear. Let us get away from the unreasonable "rule of reasonableness"—misrule of unreasonableness—which now leaves rates and returns almost wholly to the guess of commissioners. Most of them are good men, but good men are not always wise men, and even wise men should not be left to decide vast property interests without guiding principles which put all parties on notice as to their rights. Let us recognize that the inventor has destroyed the old common law rule of reasonableness, which was the rule of custom. Now the ferment of invention has, for nearly a hundred years, prevented custom from taking a "permanent set," and this ferment is destined to continue. Customary rates will not be established. Contract rates may be fixed to a limited extent, chiefly as maxima. But there is no difficulty in *fixing returns* to *capital* on a sliding scale in each contract for a public service.

And as to the final chapter, the possible taking over of a property by the public, we hear far too much about it. The old law of eminent domain seems to be forgotten. No "perpetual franchise" can hold against the right of the government to take anything it wants. No fixed term franchise can hold against that right. A grant of today may be taken tomorrow. But private property must be paid for if thus taken. Now, the terms of payment may be fixed far in advance, or may be left to a jury at any time. If we had contracts fixing possible (not guaranteed) returns on capital, those contracts interpreted in the light of actual results obtained by operation, and with known investment figures, would render relatively simple the now fearsome task of fixing a condemnation value.

I append a copy of the Bill proposed by me some years ago to cover the matter of permits for water-power construction.

(See proposed bill referred to by Mr. Crosby in hearing before National Waterways Commission, Washington, November, 1911, pages 136 and 137.)

Gano Dunn: I want to do service to a friend and to say to the Honorable Congressman that he understood Mr. Baekeland exactly the reverse of what Mr. Baekeland meant about Congress. Mr. Baekeland's experience has been the same as that of all the rest of us when we came down here—we have been received very courteously and listened to with such attention that we have been made to feel that every member of Congress or committee we have gone before has been extremely desirous of drawing out all the facts. This has caused us to revise some of our former false opinions to the contrary.

I would like to read to the Congressmen and others who may be interested, the official policy of the American Institute of Electrical Engineers in regard to these matters, especially in view of his suggestion that we develop and bring out a bill for specific suggestions as to how water-powers should be handled: "The governing body of the Institute has continued its special

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committee (on water power) in consequence of these successive invitations in view of the apparent appreciation on the part of the government that the services rendered by the American Institute of Electrical Engineers were scientific and professional and not commercial or political, that its committees dealt with fundamental engineering and economic principles of hydro-electric development that were outside the field of controversy, and that the function of the Institute being scientific and professional and not commercial or political, its status was one involving a high degree of disinterestedness in respect to matters on which its technical advice was sought."

Mr. Baekeland referred to an address which I had the honor of making before the Washington Society of Engineers some time ago, in which he mistakenly reported me as saying that engineers ought never to mix in politics and other things. What I said was that in the appointment of the Naval Advisory Board I believed for the first time in history the engineer, as such, had been invited to sit on the bench of Government with the statesman and co-operate with and help him, but I also said that the engineer should never go so far as to think that he can take the place of the statesman. The function is different and requires a different kind of man. The engineer is not big enough to do both things, and if we appointed an engineer as Secretary of State, our diplomacy would be likely to suffer. Therefore, I feel that we should stay in our own province as technical experts, and advise about the things we know, we should go before the various committees of Congress and answer inquiries about these things, but it is to them we should leave the other questions of what bills should be drawn and what kind of political bodies should be created to do the regulating and administering of the affairs of the government generally. Something toward this aim is what we hoped to accomplish in organizing this meeting here for the discussion of water-powers.

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NOMENCLATURE OF A-C. COMMUTATOR MOTORS
REPORT OF SUBCOMMITTEE No. 6

April 14th, 1916.

To the Standards Committee:

As a result of the correspondence brought about by communications to each member of the Standards Sub-Committee on the Nomenclature of Alternating-Current Commutator Motors, and to a munber of engineers interested in the subject, there were collected in concrete form the views of many persons concerning the solution of the problems assigned to the sub-committee.

An analysis of the various views has led to the selection of definitions for certain terms which, while not meeting with universal approval, are believed to be subject to the minimum of disapproval.

Herewith is sent a list of "Suggested Definitions of Terms Used in Describing Alternating-Current Commutator Motors" which it is believed will meet with the maximum of approval.

The accompanying list is submitted to the Standards Committee as the report of the sub-committee with the recommendation that the definitions be looked upon as suggestions for guidance in the selection of words to be used in describing motors of the alternating-current commutator types, but not to be considered as adopted by the Institute.

It is realized that many of the suggested definitions may be at variance with those heretofore used or which may be used in the future, and it is not intended that the definitions should be considered as interpretations where there is any variance.

Respectfully submitted,

A. S. McAllister
Chairman, Sub-Committee No. 6,
Nomenclature of Alternating-Current Commutator Motors.

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April 8, 1916.

SUGGESTED DEFINITIONS OF TERMS USED IN DESCRIBING ALTERNATING-CURRENT COMMUTATOR MOTORS

In no case is it intended that the use of any one term will exclude, or render unnecessary, the use of all the other terms. Each term is intended to refer to a certain group of alternating-current commutator-motors; any chosen motor may logically be classified under a large number of different, but non-conflicting groups. Each new term here presented relates exclusively to motors with commutators. Where ambiguity is liable to exist the word "commutator" should be used with the term.

CLASSIFICATION BY PHASES OF ENERGY SUPPLY

A. **A Single-Phase Motor** is one that receives the whole of its energy from only one phase of an alternating-current supply system.

B. **A Polyphase Motor** is one that receives its energy from a plurality of phases of an alternating-current supply system.

CLASSIFICATION BY SPEED CHARACTERISTICS

For convenience, alternating-current commutator motors can be classified with reference to their speed characteristics as (1) constant-speed motors, (2) multi-speed motors, (3) adjustable-speed motors, and (4) varying-speed motors. Definitions of these terms as given in Sections 151-154 for motors in general, should be adopted for alternating-current commutator motors, in so far as they are applicable.

CLASSIFICATION BY EXCITATION

C. **A Stator-Excited Motor** is one in which the torque-producing field is due to current in a winding located on the stator.

D. **A Rotor-Excited Motor** is one in which the torque-producing field is due to current in a winding located on the rotor—generally the armature.

E. **A Stator- and Rotor-Excited Motor** is one in which the torque-producing field is due to current in windings located on the stator and on the rotor.

F. **A Constant-Field Motor** is one in which the torque-producing field remains practically constant independent of the load. Alternating-current commutator motors of this class will in general have load-speed characteristics similar to those of the direct-current shunt motor, but not all alter-

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nating-current motors having such load-speed characteristics are constant-field machines.

G. **A Varying-Field Motor** is one in which the torque-producing field varies in some proportion with the current in the armature—generally the rotor. Such a motor will in general have load-speed characteristics similar to those of the direct-current series motor.

NEUTRALIZATION, COMPENSATION AND COMMUTATION

H. **A Neutralized Motor** is one in which use is made of a winding for producing a magnetomotive force opposed in space and in time to the armature reactive m.m.f., over practically the entire pole face.

Ia. **A Compensated Motor** is one in which means, other than a neutralizing winding, are provided, for improving the power-factor.

Ib. **A Commutating-Field Motor** is one in which a special field is introduced for improving the commutation.

CLASSIFICATION BY ENERGY RECEPTION.

J. **A Conduction Motor** is one in which the working energy is supplied to only one of the members, and, is conveyed to it by conduction.

K. **A Transformer Motor** is one in which the working energy is transmitted from one member to the other by transformer action. A motor in which the energy required by its armature—generally the rotor—is conveyed to it by electromagnetic induction or transformer action, can properly be referred to either as an "induction motor" or as a "transformer motor". Although it is equally applicable to a motor having a commutator, the term "induction motor" is usually applied to a motor without a commutator. The term "transformer motor" is therefore recommended for use with motors of the induction, or transformer type, having commutators.

L. **A Transformer-Conduction Motor** is one in which the energy required by its armature—generally the rotor— is conveyed to it by both conduction and electromagnetic induction.

M. **A Repulsion Motor** is a transformer motor in which use is made of independent brushes for short-circuiting a number of coils of the commuted winding.

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To be presented at the 327th Meeting of the American Institute of Electrical Engineers, Boston, Mass., December 8, 1916.

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RUPTURING CAPACITIES OF OIL CIRCUIT BREAKERS

BY STEPHEN Q. HAYES

ABSTRACT OF PAPER

This paper is really a series of more or less disconnected notes dealing with the question of rupturing capacity of oil breakers. It makes no attempt to go into the theory of circuit breaker design, and its main object is to open up a discussion regarding the advisability of using the term "Maximum Safe Rupturing Capacity" to describe the result obtained by the root-mean-square of the maximum peak of the current wave that occurs while the breaker is opening, multiplied by the root-mean-square of the open circuit voltage that occurs immediately after the breaker opens. Attention is called to the different ratings due to use of peak values and root-mean-square values of current voltage.

It is recommended that an oil switch or an oil circuit breaker should be given a rating on the basis of maximum safe rupturing capacity that it can handle, and that a breaker after opening a short circuit up to its rating, should be immediately reclosable, and able to again open up a similar short circuit; breaker should open three successive short circuits before contacts need be repaired or oil replaced; these short circuits may be as close as two minutes apart.

THE OBJECT of this paper is to suggest the proper basis for the guarantees to be made by manufacturers of oil circuit breakers or switches to enable the prospective user to determine the suitability of the breaker to the proposed service conditions. This guarantee should be a specific statement of what the oil switch can do, and should preferably be free from any assumptions as to reactance in circuit, generator characteristics, use of relays or similar features.

It is self evident that oil circuit breakers for large power systems must be suitable for the service they are to perform, their current-carrying parts must be ample, their insulation good, and they must be capable of rupturing any amount of current they may be called upon to open. Such breakers should not only clear the circuit, but should be immediately reoperative without the necessity of inspection, adjustment, or repair, although inspection is advisable at the first suitable opportunity.

The term "ultimate rupturing capacity," as usually employed by American switchgear manufacturers has been applied in

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such a manner that it really means the maximum size of system on which a breaker could be safely used, and even when used in this manner, it is necessary to explain fully, the basis of calculation, and the various assumptions that have been made.

It has been standard practise to assume that the breaker is connected directly to the buses, and may have to open any amount of current that can be received from that bus in case a short circuit of negligible impedance occurs just beyond the breaker. In most cases it is the reactance of the circuit rather than the resistance, that limits the current flow at times of short circuit, so it is usual to consider the reactance rather than the impedance of the circuit in calculating current flows. For cable systems or high-tension transmission circuits, the capacitance has to be considered. All of the generators and other synchronous apparatus connected to the bus, will tend to feed into the short circuit whatever current they can deliver under these conditions, this current as a rule, being limited only by the inherent reactance of the machines, and any external reactance that may exist between the machines and the point where the short circuit occurs. This method of rating, involves the momentary and sustained short circuit characteristics of the machines, the various reactances in the circuits, the speed of tripping of the breakers and other similar features.

Whether a breaker is to be used for automatic or non-automatic service, it can only open a certain fairly definite amount of power at the arc. This amount being fixed, it should be noted that for non-automatic service, the size of plant to deliver this would be determined by the sustained short circuit characteristics of the generators, and other synchronous apparatus. For automatic service, this same amount of power could usually be delivered by a smaller plant, as the momentary short circuit current is almost always higher than the sustained.

In order to allow for certain of these variables due to the machine characteristics, one American manufacturer gives ratings for his oil switches for automatic and non-automatic service for two classes, A and B, the latter being systems where one or more generators are of the turbo type with reactances of less than 8 per cent and the former applying for all other systems.

Another American manufacturer explains the ratings assigned by using a standard assumption of generators or other synchronous apparatus, having an average reactance of 8 per cent, a momentary short circuit current of 12 ½ times normal falling

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to half of this amount, or $6\frac{1}{4}$ times normal by the time the breaker opens, and a continued short circuit of one quarter, or three times normal. With this explanation, it is evident that a breaker rated as having 10,000 kv-a. rupturing capacity should be capable of handling 62,500 kv-a. at the short circuit. This same breaker for non-automatic service where the machines are assumed as delivering three times normal, could, therefore, be used on a 20,000 kv-a. system, or would have a non-automatic rating of 20,000 kv-a.

In systems of large generating capacity, where current limiting reactors are used, or where the reactance of transformers and lines may limit the current flow on short circuit to a point well within the capacity of the system to supply continuously, it will be found that the breakers provided with time limit relays, or used for non-automatic service, have as severe rupturing conditions to meet as those used for automatic service.

These methods of rating are not directly applicable in all cases, and are open to many objections, and do not readily take into account certain features that really are vital in determining the adaptability of breakers to specific service. The rate at which the short circuit current of a generator dies down varies with its design, so that the short circuit current of a generator may die down from the initial rush to the continuous short circuit value in a period of time ranging from 0.2 to 0.8 seconds. The initial wave may be as high as 20 times normal, and the continuous short circuit value may be as low as 1.4 times normal.

Due to inertia, it is impossible to have a breaker trip out instantaneously, consequently no breaker is ever called on to open the momentary short circuit current that occurs during the first few cycles, but it has to be strong enough mechanically to resist the magnetic stresses set up during such a short circuit. With a-c. coils energizing the mechanism direct from the current transformers, large capacity breakers can be made to open in about 0.2 second. With the usual shunt trip relays, the time of opening is about 0.3 to 0.5 seconds, while with time limit relays, the opening can be delayed either for some definite time, or for a time that varies inversely with the load. With a non-automatic breaker, the time of opening is left to the discretion of the operator. As most generators reach the condition of continuous short circuit current in not over 0.8 seconds, it is figured that a definite time limit of two seconds or even less, secured through a relay, is equivalent to non-automatic service, in so far as rupturing requirements are concerned.

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In order to simplify this question of breaker rating, it is proposed to use "maximum safe rupturing capacity," or some similar term to describe the result obtained by the root-mean-square of the maximum peak of the current wave that occurs while the breaker is opening, multiplied by the root-mean-square of the open circuit voltage that occurs immediately after the breaker opens.

All modern transmission systems employ generating apparatus giving essentially a sine wave for current and voltage, which sine wave has a ratio of peak value to root-mean-square value of 1.4 to 1. A breaker capable of rupturing 10,000 amperes maximum value at 10,000 volts maximum value, if rated on the root-mean-square basis, would be considered capable of handling 7100 amperes at 7100 volts, or would be given a rating of 50,000 kv-a. If the peak value of the current, or 10,000 amperes, is used with the root mean square value of the voltage, or 7100 volts, the rating would be 71,000 kv-a. If the peak value of the current, or 10,000 amperes, is used with the peak value of the voltage, or 10,000 volts, the rating would be 100,000 kv-a. All of these ratings would cover the same duty to be performed, but as all power measurements are regularly based on the root-mean-square values of current and voltage, this is undoubtedly the logical basis for circuit breaker rating.

In case of an unsymmetrical wave, experience seems to show that the strain of opening does not differ appreciably from that produced by a symmetrical one. A current wave ranging from a positive maximum of 10,000 amperes to a negative one of 2000 amperes can be taken care of as readily as one ranging from plus 6000 to minus 6000. This may be due to the longer time required for the arc to reestablish itself in the case of the unsymmetrical wave where the negative maximum is small. By the time the breaker actually opens the circuit, the amount of assymmetry has greatly diminished from that experienced during the first few cycles.

It might be pointed out that there is a difference between rating a circuit breaker in terms of the maximum kv-a. which it can open, and in terms of the maximum current which it can open. On certain systems with the machines of certain characteristics, heavy short-circuit currents are usually accompanied by reduced voltages and this point has to be given careful consideration. After opening a very heavy short circuit, thus relieving the system, the voltage frequently has a tendency

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to rise immediately to a point somewhat greater than normal, and this point should also be considered in the rating of the breaker; in other words, a certain breaker might be able to open 10,000 amperes successfully where the circuit voltage immediately after the short circuit only went back to normal, whereas it might not be able to function satisfactorily if the open-circuit voltage went up to points considerably above normal.

It is realized that it will be extremely difficult for an engineer to determine in advance exactly how heavy a short circuit it is possible to get at a given point on a transmission system, but from the view point of the manufacturer, it is simpler and better for him to make a definite guarantee as to just what service his breaker can accomplish, allowing the operating or designing engineer to determine whether such a breaker will meet the actual short-circuit conditions that may occur on any point of his system.

Almost all of the oil switches and oil circuit breakers now in service, are operating satisfactorily, but it is realized that they are far from perfect, and it is possible that some of the commercial breakers being sold, are over rated. By having some definite rating in kv-a. to work to, breakers of the smaller sizes could be tested to see that they actually met their guarantees.

The kv-a. rating obtained as above is that which this breaker should be guaranteed to open, the breaker being immediately reoperative, without the necessity of replacement of oil or adjustment of contacts. It might be well to fix this rating at such a point that the breaker could be guaranteed to open this amount at least twice, and to be immediately reclosable, and in condition to open the same circuit kv-a. the third time.

In a-c. railway work, and similar installations where repeated short circuits are apt to occur, the breaker should be capable of opening such a short circuit at least ten times within the course of an hour; such short circuits not occuring closer together than two minutes to allow time for the gases that may be formed due to the short circuit to be properly vented from the breaker before a second short circuit occurs.

As most power circuits are three phase, the rupturing capacities assigned to circuit breakers are those applying to three-pole breakers on that service. The corresponding rating for two-pole breakers on a single-phase circuit is 70 to 75 per cent and the rating of a four-pole breaker on a two-phase circuit is considered 140 to 150 per cent of the corresponding three-phase rating.

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Under some certain conditions, smaller switches could be used, for instance, in substations where limited transformer capacity is installed between the oil circuit breaker, and the line, or on substation feeders where a breaker of higher capacity is interposed between the breaker in question, and the substation bus.

When considering switches for connection to buses fed from the generator units of motor-generator sets, the capacity of the system supplying energy to the motor-generator set, need not be considered. In such cases, the sum of the rated capacity of the generator units, on the motor generator sets should come within the limits assigned to the breakers.

The kv-a. ratings usually assigned to breakers are based on the listed voltage rating of such breakers, and any change in operating voltage from the listed voltage rating will usually change the kv-a. rating in about the same percentage, that is, an increase or decrease in voltage of 20 per cent would decrease or increase the kv-a. rating by the same amount.

While this percentage rule is not strictly adhered to, a typical example might be noted of a certain moderate capacity breaker designed for 22,000 volt service with a nominal rupturing capacity, assigned by its builders, of 10,000 kv-a. at 22,000 volts, 12,000 kv-a. at 16,500, 13,000 at 13,200, 17,000 at 7500 and 19,000 at 4500 volts or less.

It is a well known fact that the opportunities of testing the actual rupturing capacities of the largest capacity oil switches and breakers are almost nil and that the capacities assigned are really intelligent estimates based on the testing to destruction of small units and calculation as to the increase in rupturing capacity secured by greater volume of oil, greater head of oil, increase in strength of tanks, extra volume of expansion chamber and similar features.

On the assumption, more or less justified, that the strength of the breaker tops, insulators and fittings have been properly proportioned to the tank strength and that the speed of opening is satisfactory the rupturing capacity of an oil breaker may be considered as a function of the tank dimensions.

Where a breaker has been installed, it should be remembered that with increase in capacity of system, failure to maintain breakers either as regards mechanism or insulation, changes in reactance, changes in method of operation and defective relays may so change the duty on a breaker as to lead to its destruction.

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DISCUSSION ON "REPORT OF TRANSMISSION COMMITTEE," CLEVELAND, OHIO, JUNE 27, 1916. (SEE PROCEEDINGS FOR JUNE, 1916.)

(Subject to final revision for the Transactions.)

N. A. Carle: I think that in general it is recognized that higher temperatures occur in transformers, motors and generators at altitudes above 600 feet than for the same loads at sea level. At the present time, I understand, the Standards Committee of the Institute is trying to determine a suitable corrective factor or formula to meet this condition.

M. O. Troy: Mr. Carle has correctly summarized the matter when he says that correction for altitude is one of small magnitude.

Operating men, who in the past have bought electrical apparatus with reasonable margins of safety, in all probability have not noticed any effect of altitude, and for that reason so state in their reports. If, however, they had measured their loads and capacities carefully and compared the heating values so obtained with those obtained by the manufacturers—in all probability at lower altitude—they would have found a difference.

In the standardization work of the Institute, we have tried to establish safe but definite temperature limits of operation.

I think there is no doubt that modern apparatus working at sea level to the limits prescribed by the Institute will exceed those limits if the apparatus is operated at the high altitudes under discussion; and if the sea-level temperatures represented a maximum for the safe operation of certain classes of insulation, the temperatures at the high altitudes would go beyond safe allowable limits.

Correction factors, therefore, should be recognized and definitely established by the Standards Committee as soon as reliable data are available.

Peter Junkersfeld: Our experience in Chicago with the grounded neutral covers the past fifteen years. The first experience was the initial installation of the four-wire three-phase system of primary distribution operating at 2300/4000 volts, 60-cycles. This system was extended so rapidly that in a few years it absorbed all of the older single-phase generating stations, and has since been the standard arrangement in the Chicago territory.

Within a year after our initial experience on the 60-cycle system the voltage on the 25-cycle system was raised to 9000 volts and the neutral grounded, which has since then been standard practise on that system.

Both of these systems have grown so rapidly that the experience in Chicago with grounded neutrals has been quite extensive during the past fifteen years as may be illustrated to some extent by the mileage of cable or conductor operated with grounded neutral, which at this date is as follows:

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9000-volt,	25-cycles,	3-phase	cables	undg.	485	miles	(781 km.)
20000 "	25- "	3- "	"	"	83	"	(132 km.)
12000 "	60- "	3- "	"	"	158	"	(254 km.)
					726		

2300/4000-volt, 60-cycle single conductor equivalent underground 1518 (2444 km).

2300/4000-volt, 60-cycle single conductor equivalent overhead 7850 (12638 km.)

The reason for stating the last two in conductor miles is that there are a considerable number of single-phase branches connected to the three-phase four-wire circuits. In such cases and also on some other circuits single conductor instead of three-conductor cable is used.

The 25-cycle 9000-volt system is supplied by turbo-generators ranged in capacity from 12,000 to 30,000 kw. This system is divided into sections, so that the generator capacity connected to the largest section does not exceed 80,000 kw. Three of these sections are interconnected by tie lines with protective reactance coils, while the fourth section is connected to the system by means of underground tie lines about 8.3 miles (13.4 km.) long without reactance coils. Our standard practise is to have the neutral grounded on one turbo-generator of each of the four sections. The neutrals are grounded through iron grid rheostats having a resistance of $2\frac{1}{2}$ ohms. One of these rheostats is provided for each system section, and is connected between ground and a neutral bus, which can be connected by means of an oil circuit breaker to the neutral of any turbo-generator on that system section.

The neutrals of the 12,000-volt 60-cycle turbo-generators are grounded in a similar manner through iron grid rheostats having a resistance of three ohms.

The energy for the 2000-volt 25-cycle system is supplied by means of three 5000-kw. three-phase transformers stepping up from 9000 to 20,000 volts. The primary is delta and the secondary is star connected with the neutral of all three transformers grounded solid.

The 2300/4000-volt 60-cycle system is supplied by 25- to 60-cycle frequency changers and 1200-volt to 4000-volt three-phase transformers. The transformers are delta on the primary and star connected on the secondary. The neutrals of the 60-cycle generators of the frequency changers are all connected solid to ground, and the same is true of the neutrals of all of the transformer secondaries.

The experience with grounded neutral on the above systems has been very satisfactory, the principal benefits having been the following:

1. It insures the prompt automatic disconnection of any faulty feeder.

2. It prevents the existence of delta voltage to ground on

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other lines and apparatus in case of a ground on any part of the system.

3. It helps in locating breakdowns of lines and of apparatus.

4. It prevents arcing grounds and therefore voltage disturbances.

It must be noted that the last statement refers to specific conditions. Under some conditions differing from these it may not always be advisable to ground the neutral. I with several other engineers made a rather extensive inquiry a few years ago as to the advisability of grounding the neutral on 33,000-volt overhead lines connecting cities and towns in Illinios. In this case it was decided to install a delta connected system without grounded neutrals, except in such few special cases as might later prove to be advisable. The reasons for that decision were as follows:

1. The general secondary distribution system was four-wire 2300/4000 volts. As this necessitated a star connected secondary on the step down transformer, acknowledged good practise determined a delta connected primary on these transformers.

2. On account of consolidations, it was necessary to operate in parallel a number of different properties, and because of phase relations it was found most advantageous to have the step up transformers at the generating stations star connected on the primary and delta connected on the secondary.

3. The argument, that with an ungrounded neutral the system could be operated in emergencies with one phase wire grounded, had considerable weight.

The 33,000-volt lines have been built so rapidly during the four years since the decision referred to was made that they now aggregate 1000 miles (1600 km.) in Illinois alone. These lines are not all owned or operated by the same companies, but in this matter and in many other matters follow the same principal engineering standards.

I will repeat, that on the overhead system the experience is still too limited to draw absolutely final conclusions, but as far as the underground system is concerned, covering a period of fifteen years and the large mileage mentioned, we feel under those conditions that grounding of the neutral has proved a wise course.

E. E. F. Creighton: There are some cases where the neutral can be judiciously grounded, and there are other cases where it is better not to ground it, if the proper precautions are taken. The greatest objection to a non-grounded neutral at the present time is the arcing ground, and the result it gives on the system.

David B. Rushmore: In connection with the installation of the various transmission systems in this country, there has been a continual discussion regarding the relative merits of grounded Y and ungrounded delta transformer connections. As electrical apparatus, and especially lightning arresters, have de-

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veloped the situaton has undergone different modifications, so that in some places one and at other times the other connection has seemed desirable.

Transmission systems have, as a rule become high-tension distributing systems, and the network of overhead wires has become greatly extended and the load situation much more complicated. The important question of operating so as to deliver continuous service has brought about the development of automatic relays, so that disturbances may be instantly localized. For this purpose the use of the grounded Y has many decided advantages and, in most cases, at the present time is to be recommended.

N. A. Carle: The preponderance of opinion seems to be against the grounded system. We in New Jersey have a lot of transmission lines there, and have an undergrounded system which is very satisfactory.

J. T. Lawson: The system mentioned by Mr. Carle operates at 60-cycle, 13,200 volts with an ungrounded neutral, and is equipped with an arcing ground suppressor.

Mr. Rushmore, if I understood him correctly, brought out the point of non-interruption to service on a grounded neutral system. With an ungrounded system equipped with an arcing ground suppressor, I think you come closer to this condition than without the use of the suppressor. Instead of having a cable open at both ends thus shutting off the service, with the arcing ground suppressor it is possible to leave the grounded cable in, parallel it with another cable, or take it out, with no interruptions to service.

The action of circuit opening relays, possibly, with the grounded system may be more satisfactory, but with single-phase arcs to ground I do not see where fine relay adjustment is necessary if the arc is extinguished before it has a chance to develop into a short circuit.

David B. Rushmore: My remarks applied mainly to high-voltage systems, 100,000 volts and over.

John B. Taylor: The detailed experiences contributed on operation of three-phase transmission systems with, and also without, neutral grounded, are of interest and value. The Committee's conclusion that for different cases, grounding "may be an advantage in some and a disadvantage in others",—is quite in agreement with previous discussions of the same question.

N. A. Carle: We have a balanced potential relay, and the unbalancing of one phase to ground puts that cable out of business, and we simply get it afterwards on tests, and another cable goes in.

John B. Taylor: You determine that unbalancing, I assume by an arrangement of potential transformers connected to your bus bars and also connected to ground, which means that your system is grounded,—you have a neutral ground on the system,—that neutral ground is made on relatively small potential trans-

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formers instead of on relatively large generators, but, technically, the system is grounded on account of the potential transformers connected in Y with their neutral grounded.

N. A. Carle: There is only one connected with the relay which makes an artificial ground through the oil switch.

P. H. Chase: I think I can explain that point. The grounded neutral system is so-called because the ground is of sufficiently low resistance that the current to ground operates a relay on the grounded phase. This is distinguished from the ungrounded neutral system with a suppressor, in that the three potential transformers which are connected in star with the neutral grounded allow only the exciting current of the potential transformers to flow to ground. Though there is this metallic connection to ground, the system with a suppressor cannot properly be classed as a grounded neutral system because the exciting current of the potential transformers is not of sufficient magnitude, and is not intended, to operate the overload relay on the grounded cable.

John B. Taylor: It seems finally to come to a definition of technicalities.

E. E. F. Creighton: If we add to Mr. Taylor's remarks some figures, it may help to straighten out the matter. The current to ground in potential transformers is a small fraction of an ampere. The current that reduces one phase of this system to ground is over sixty amperes. It would take more than forty amperes to reduce it to half potential to ground, and, therefore, I consider the system is non-grounded, even though the potential transformers are connected to ground at the neutral, because they could not in any way maintain the neutral at grounded potential.

H. R. Woodrow: Our experience has not shown that any advantage from surges has been gained by grounding the neutral of the system. The neutral of our sixty-cycle system was grounded more than two years ago and we have never been able to find any difference in surges before and after grounding. The 25-cycle system has never been grounded and we have never had any serious disturbance due to high-frequency service.

In a case of some 15,000-volt cables, the failures looked rather suspicious of surges, and we therefore grounded the neutral of this system in an attempt to reduce the surges. The result which we have obtained in the last year and a half, since this system was grounded, shows scarcely any difference in the characteristics or number of failures.

In the ungrounded system we have the grounding relay protection with a grounding transformer, which will indicate a ground on any feeder, so that the defective feeder can be taken out of service before it develops into a short circuit.

Edmund C. Stone: The system I am familiar with is a system of about 175 miles of 11,000-volt transmission, three-phase. About fifty miles of that is underground. We find that nearly

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all of our troubles originate in the overhead system and set up arcs in the grounds which break down the cable system. I think where the system is entirely cable probably that trouble would be eliminated, but we have a great deal of trouble from arcing ground originating in the overhead system, which set up voltage disturbances, and in turn break down the cable system. We have decided to adopt a grounded neutral on the theory that saving the cable is more important—the downtown system is all underground— than maintaining continuous service on the overhead system.

So far we have never had a case in five years where we have been able to operate the system with one phase of the overhead grounded. That seems to be the main recommendation for the three-phase system, and I would be interested to know if there are many examples on record where the three-phase system is actually operated and profitably operated, when one phase was temporarily grounded,—that is an arcing ground starts and creates such a disturbance that it puts us out of business until we have isolated the defective line.

Fred L. Hunt: I can tell you of a 66,000-volt three-phase circuit which within the last month operated three hours carrying a 4000-kw. load with one wire broken, the two ends of the broken wire being about 150 feet apart on the ground. The load was carried in this way until a steam plant could be pressed into service to relieve the line.

L. N. Crichton: Mr. Stone's remarks remind me of a case where the records of a transmission company covering a period of several years' operation were studied, and only two cases found where power was supplied with one wire on the ground, and even in these cases the service was finally interrupted before the ground was located. An interruption is not caused by the ground itself but by the disturbances which it creates, a single ground often causing several insulation failures at widely separated points on the system. The principal difficulty in the case of an undgrounded neutral system is that you can not locate an accidental ground, the only way of doing it on a system of any size being by cut and try methods, which with the telephone out of service is a difficult job, and the chances are good that before you get through with the process you will interrupt practically the entire system.

Now this applies only to large systems, say a 45,000-volt system, having 1,000 or possibly 1,500 miles of line. With a small system, no matter what the voltage may be, or with a simple system, say only two parallel lines, with a substation on one end and a generating station on the other end, the chances of operating with one wire grounded are very good. The reason why the large system suffers more than the small one is not because the voltage strains are greater but because there are more weak points which are liable to be damaged. As a rule, these weak points occur in apparatus rather than on the lines, there-

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fore, the amount of apparatus connected to the system is of more importance than the number of miles of circuit. If the neutral is grounded the voltage strain will be reduced so that the disturbance will not cause such widespread damage and every ground will be promptly disconnected by the automatic circuit breakers.

R. F. Schuchardt: I suggest that Mr. Hunt tell us in connection with the case he cited, something as to the nature of the soil the wires fell on, whether it was in wet grass, or sandy soil, or what the character of the soil was.

Fred L. Hunt: It was in the Connecticut Valley, in Western Massachusetts, in sandy soil. The grass and brush in the vicinity were set on fire and we were notified of the trouble by a farmer who said his field was on fire. The wire fence around the field seemed to be charged and showed signs of heavy static discharges.

E. T. Street: We have operated 13,000-volt lines with one wire on the ground, supplying power to our substations until we were able to switch over to another line. It has been my observation when we have had lines on the ground—we have had two wires down within one foot or eighteen inches of the other on sandy soil—that the breakers would stay in. With the ungrounded system we can have wires down without causing any interruption to our system as a whole.

Harold Goodwin, Jr.: As to whether the New Jersey system is a grounded neutral system or not, it seems that the committee might do the members of the Institute a service by defining for future discussion whether we shall consider such a system as grounded or not.

W. A. Carter: We had a case where one wire came down on a 100,000-volt transmission line. We buy our power from the Colorado Power Company. The power station was about thirty-five miles away. With one wire carrying current through the ground at the broken span we were able to get several thousand kilowatts, which added to the load carried by our steam plant was sufficient to carry our evening peak load.

Bernard Price: The scheme with which I am connected is controlled by two power companies, viz., The Victoria Falls & Transvaal Power Co. Ltd., and the Rand Mines Power Supply Co., Ltd., the latter being a subsidiary of the former. For present purposes the transmission and distribution systems of the two concerns may be treated as one because they are inter-connected and are operated as one system. The district is at an altitude of nearly 6,000 feet above sea level and is prone to severe lightning storms during at least six months out of the twelve and the major portion of the system is overhead.

For a system of our type, it is unquestionably wise to earth the neutral. Instances have arisen where a certain portion of the system has become insulated from earth during a lightning storm and the result has always been a very large increase in the

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number of faults. Whilst I realize that each scheme should be dealt with on its merits, I find it most difficult to conceive any overhead network in a lightning district which would not benefit by an earthed neutral.

Our experience of running the system with the neutral grounded has been most satisfactory and has shown conclusively the advantages to be derived from such grounding on a system of the type in question. In the early stages of development of the scheme, the system was run with an insulated neutral and the change to a grounded neutral removed many of the difficulties which we had encountered. Since the neutral was grounded instances have occurred where a portion of the system has become insulated at the neutral during a lightning storm and on such occasions a largely increased number of flash-overs has occurred.

Before the system was earthed, any line fault produced heavy surging with consequent flash-over from live conductors to iron work at various points in the switchgear and arrester gear. Since the neutral has been earthed, these troubles have virtually disappeared. When the system was insulated a fault from one phase to earth did not operate the automatic cut-outs but caused the arrester gear to discharge continuously. This continuous discharging heated the water resistances which are connected in series with the horn gaps of the arresters and as a consequence the discharge at the horn gaps became increasingly vicious until finally something had to give way. Frequently the arc at the horn gaps jumped to neighboring iron work, thus producing a short circuit through the original fault. Great trouble was also experienced due to flash-overs at points on switch-gear and apparatus caused by the surging produced by an arcing ground at the original fault.

By grounding the neutral the automatic cut-outs were able to instantaneously isolate the initial fault. Lightning arrester gear was no longer called upon to continuously discharge and flash-overs on switchgear connections and apparatus became a negligible quantity.

It is of course essential that each separate section of the system shall be separately grounded and provision must be made to ensure that when portions of the system become automatically isolated from other portions, they still remain grounded.

The grounding of the neutral is the only means we adopt for preventing a static rise of potential. In the dry season, during which winds are prevalent, serious rises of pressure would no doubt occur if the neutral of the system were insulated but we have experienced no trouble in this respect since the neutral was grounded.

As already mentioned, the benefits which have been derived from the grounding of the neutral have not been solely due to such grounding but have really been the result of the combination of a grounded neutral with the adoption of differential relays controlling the cut-outs.

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With regard to the points at which grounding should be introduced, we have found that generally main generating stations serve the purpose quite satisfactorily, the advantages being as follows:

1. The grounding being at the source of supply there is a minimum length of line between the fault and the source of supply, thus decreasing the total impedance to earth and in the case of a large network, this factor becomes important. In some cases it may be found necessary to introduce more than one ground so as to compensate for the high impedance of the lines where these are unusually long. In practise we have found this to be the case.

2. The grounding resistance being at generating stations, is subject to constant supervision and thus is liable to be kept in a more efficient condition by routine inspection and overhaul, and moreover, can be repaired quickly in case of breakdown with a minimum cost.

3. If the step-up transformers at the station be designed with delta-star connections (the low tension in delta), then grounding can be easily accomplished (without the expense of installing a special earthing transformer), by earthing the star point of the high-tension side.

On the question as to whether a resistance should be inserted in the neutral connection, it may be argued that if the neutral is grounded without a resistance, the pressure rise to earth on the two healthy phases (assuming one phase is earthed through insulator breakdown or other cause) is reduced to a minimum. Grounding solidly, however, results on a fault from one phase to earth, in the production of a dead short circuit with consequent danger to switchgear and other apparatus. The principle we have adopted is to insert resistance of a value as low as safely possible, having in view the condition that the current flowing to any fault must be ample for operating the automatic cut-outs. In this connection it may be found necessary to lower the value in order to compensate for the high impedance of long lines as previously explained or, what amounts to the same thing, to instal another grounded resistance at some other point on the particular section of the system. For example, the ground resistance of the Brakpan 20,000-volt overhead network is 14 ohms and quite satisfactory results have been obtained in practise, but in the case of the Bantjes 20,000-volt overhead network it has been found necessary to have two separate grounding points each of 14 ohms and about 13 miles apart. Originally only one ground resistance was provided at Bantjes distribution station (see Fig. 1) and the experiment was tried of reducing the resistance until ultimately this was brought down to 8 ohms. No marked improvement was however effected owing to the high impedance of the lines between Bantjes and Luipaardsvlei and finally, another grounded resistance was installed at West Rand No. 2. Although no trouble has since been experienced, we are

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awaiting the results of another lightning season before forming a definite opinion.

In regard to the construction of the resistance, our experience is confined to two types, viz., metallic grid resistances and water resistances and has shown that water resistances are undoubtedly preferable to the metallic type. The latter are liable to burn out in the case of a sustained fault on the system, *e. g.* high resistance fault to earth. This results in great inconvenience especially

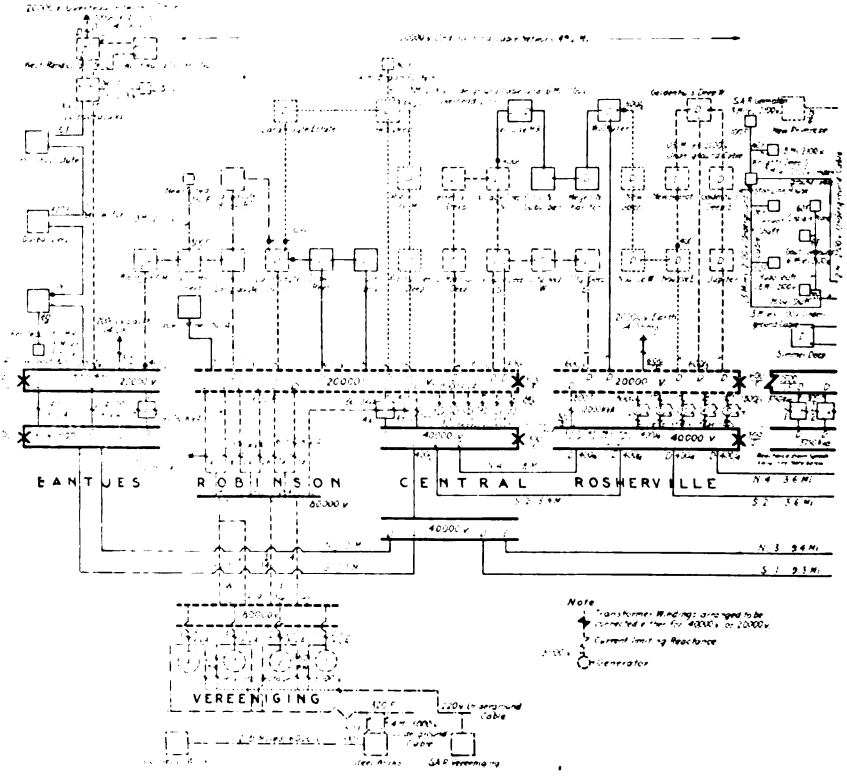

FIG. 1—DIAGRAM SHOWING SECTIONALIZATION OF SYSTEM OF 3-PHASE

if it occurs at the commencement of a lightning storm, as the benefit of the grounded neutral is thereby eliminated for the remainder of the storm. We have experienced no trouble with the water resistances but care must be taken to ensure a sufficient body of water and also to provide for a large metallic surface on the entering terminal so as to prevent undue heating and possible boiling of the water. The water resistance we use consists of a large tank about 7 ft. high and 12 ft. in diameter having a submerged terminal of considerable area suspended from an

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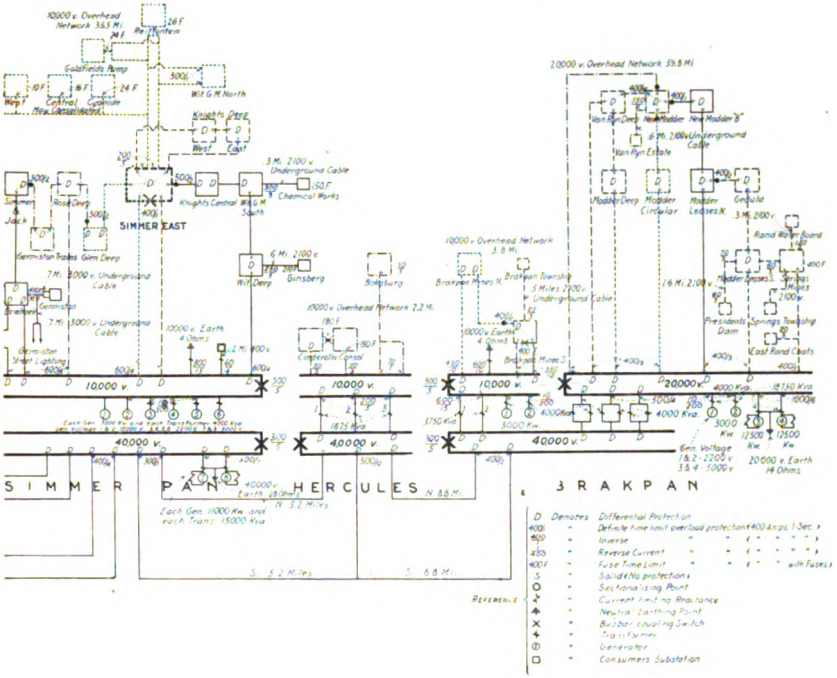
nsulator on an erection over the water. Such resistances are placed outside on the ground without housing.

We find that metallic grids require constant supervision whereas the water resistances can be left for a period of six months or more without the value of the resistance altering 10 per cent. The resistance moreover can be varied at will with comparative ease and in first cost is considerably less than the metallic type unless very large resistance values are required.



THE VICTORIA FALLS AND TRANSVAAL POWER COMPANY, LTD. 50-CYCLES.

In reference to the earth connection, it is our practise to connect the earth side of the resistance to the station main earth and this has proved quite satisfactory, as in all cases the latter tests out at less than 0.2 ohms.

No difficulty is experienced in obtaining a good earth at power stations as all our stations are associated with a large expanse of water and large metallic plates sunk in the water provide a good earth at all times of the year.

The combination of an earthed neutral (through resistance)

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with the differential system of automatic cut-outs has greatly reduced the insulator troubles.

It must be remembered that the majority of our insulator troubles are caused by lightning and as the system is subjected for nearly six months in the year to very severe lightning effects, the matter is of much importance. Owing to the combined action of the earthed neutral and the instantaneous operation of the differential relays the lines which trip out due to lightning flash-overs are in the majority of cases, fit to close it again because the arc at the insulator has not had time to permanently damage the insulator.

Moreover, we find that the number of insulator faults is considerably increased if the system be run during a severe storm with the neutral ungrounded, due no doubt to the secondary surging which is set up finding out the weaker insulators.

Our experience is that no disturbance to telephones is produced, providing the windings of the earthing transformer are star-delta. We find that we can safely ground the neutral at two distant points with only a small interchange of current and no secondary effects.

If the system is not earthed through a star-delta transformer very violent disturbances are produced on all telephone circuits in the neighborhood of the transmission lines.

Fig. 1 shows the electrical layout of the high-tension lines and apparatus and also the location of all protective devices, current limiting reactances and points of earthing.

It will be seen that the whole system is subdivided into a number of separate networks each laid out on the ring-main principle, thus ensuring at least a duplicate supply to every consumer over divergent routes.

Practically all lines are equipped with Merz-Price differential gear but main feeding points and certain sectionalizing points are equipped with difinite time-limit overload relays, also nearly all generators and all transformers are differentially protected.

Our experience has clearly demonstrated the remarkable discriminating qualities of the differential method of protection and owing to its simplicity and rapidity of action, every piece of faulty apparatus, whether it be a line transformer or generator, is instantaneously isolated with minimum disturbance to the system. It is a feature of this method, however, that individual pieces of apparatus are separately protected and as a consequence a fault on the busbars does not come within the control of the differential relays. Such faults are or should be extremely rare but in order to limit their effect upon supply, the networks are divided up into sections, each section being under the control of definite time-limit relays at the points where it is fed and where it is inter-connected with neighboring sections. Inverse-time-limit overload relays are in use at a few points where discrimination with other relays is not required. Our experience has proved that on a large power system such relays are of little value as

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a discriminating device. Reverse-current relays are in use on a few points such as generators not provided with differential protection and isolated lines not forming a part of a ring-main network and not differentially protected.

It will be noticed in Fig. 1 that the setting of the definite time-limit overload relays at different points on a network is such that under heavy fault conditions the network is automatically sectionalized, each section capable of a separate existence, *i. e.*, each of these sections has sufficient feeders to deal with its particular loading. These conditions apply to the worst type of fault, namely, a busbar fault at a substation, all feeder faults being dealt with instantaneously by differential protection and without operating overload relays at other points.

In the event of a sustained fault on consumer's premises the substation transformers are tripped off by the simple device of a small fuse inserted in the secondary circuits of the differential relays. This fuse blows with small time element and brings the instantaneously acting differential relay into operation thereby tripping the transformers without operating overload relays at other points on the system. Faults of this kind frequently occur and the supply to the consumer's fault is always isolated without affecting the supply to others.

We use the current flowing to ground at the neutral connection to indicate when a fault to earth occurs. For this purpose a recording ammeter is connected to the secondary side of a current transformer in the earth connection. The results obtained are purely qualitative.

From tests taken with the oscillograph, we have found that under normal operation the magnitude of the current flowing to earth through the neutral is relatively small and of no practical importance.

We have also found that with the neutral earthed simultaneously at two different points, the interchange of current is not appreciable enough to be serious. For example on the 40,000-volt system with the neutral earthed at Simmerpan through 28 ohms, the r.m.s. value of the current was found to be about 1 ampere and the current flowing through the neutral of the Simmerpan 10,000-volt network (neutral resistance 7 ohms.) less than 0.2 amperes.

The oscillogram of the former showed the presence of at least the 13th harmonic and the latter showed the presence of at least the 23rd harmonic.

With the neutral of the 40,000-volt system earthed at two distant points, we found the presence of a comparatively large amount of even harmonics, the 6th being predominant and over 20 per cent of the fundamental in value and in phase with it.

The following is a short description of the various types of relays in use on the system:

Differential Relay. This device as used on our system is a three-phase three-pole relay consisting essentially of a three-pole armature rotating in a three-pole field system.

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The latter is energized from the secondary side of the differential protective current transformers and causes the movement of the armature.

The armature in its rotation releases a weighted contact arm which closes the switch tripping circuit.

Definite Time-Limit Overload Relay. This relay is made in two parts one part consisting of an overload relay and the other comprising the definite time-limit mechanism.

The overload relay is similar in design to the three-pole differential relay, excepting that the impedance of the coils is much greater.

The definite time element portion commences to operate when a d-c. circuit is closed by the overload portion which starts the clock-work mechanism. After the pre-determined time has elapsed the relay closes the switch tripping circuit.

Inverse Time-Limit Overload Relay. This relay is of the ordinary induction type instrument and the armature, consisting of the usual metal disc, rotates in a field system energized by the secondary circuit of the line-current transformers. The relay is single-phase and three are required for full protection.

The time element is obtained by varying a tension spring controlling the armature.

Reverse-Current Relay. The reverse-current relay (or more correctly reverse-power relay) is exactly similar in construction and operation to the inverse-time-limit overload relay excepting that it has pressure coils in addition.

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To be presented at the 327th meeting of the American Institute of Electrical Engineers, Boston Mass., December 8, 1916.

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RATING OF OIL CIRCUIT BREAKERS

BY E. M. HEWLETT

ABSTRACT OF PAPER

Paper points out several difficulties, which are encountered in the rating of actual circuit breakers, but generally favors that these ratings be on the basis of the current to be opened in the arc at the operating voltage of the system.

THE VARIABLE factors entering into the problem of rating oil circuit breakers make its solution very difficult.

Up to certain capacities it has been possible to determine definitely what oil circuit breakers will open. The experience of many years, during which oil circuit breakers grew from a few thousand volts for a few kilowatts station capacity, to 10,000 volts, 40,000 volts and higher voltages, for many thousand kilowatts station capacity, coupled with the facilityof testing various designs under actual emergency conditions, has crystalized the requirements of circuit breakers of this kind and the constructive features of commercial design.

However, the capacity of stations is always growing, the forces dealt with are ever increasing, and consequently, new types of circuit breakers must be constantly developed, ratings of which cannot be based on actual past service. To test such circuit breakers systematically would be beyond the scope of any testing units at the disposal of any manufacturing company and would require the use of power stations of enormously high capacity.

The possibility of utilizing such power stations for the testing of circuit breakers is very limited, as in order to carry their connected load the big operating companies must generally have constant and instantaneous control of all their apparatus.

Thus, new designs of high-duty circuit breakers must, for the present, be rated mainly upon judgment based on past broad experience. For the engineer, the ideal way of rating circuit breakers is on the basis of the current which is actually opened

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in the arc at the operating voltage of the system, as in the present A. I. E. E. ruling. (This current in the arc is not the peak value of the short circuit current curve, but is that value which prevails at the moment when the circuit breaker opens, at the point where it is installed.) However, in a rational design of circuit breaker, other factors must be considered besides current to be ruptured, primarily the power factor at the time of the event and the voltage regulation of the system. In the smaller capacities, these factors could be disregarded, as with them it has always been possible to allow very liberal safety factors without sacrificing reasonable proportions. We are therefore rating at the present time oil circuit breakers by arc current and system voltage up to certain capacities. As the capacities of the system and circuit breakers increase, as spacings and clearances become important design factors, and as materials employed in the construction of the circuit breakers must be used more nearly to their limits, it becomes necessary to take all conditions into account.

Oil circuit breakers for small stations and industrial service are often used by men who should not be called upon to figure the current and voltage values, which is necessary for selecting the proper type circuit breaker for their service.

For these conditions the kilowatt rating is most convenient, *i.e.* the total generating capacity of the system, or its equivalent, at the point of disturbance. Generally the kilowatt rating is based on the assumption, that the disturbance takes place so close to the generating apparatus, that reactance and resistance of connections between generating apparatus and the place of disturbance need not be considered. A certain initial reactance of the generating apparatus and a certain diminution factor of the current started by the disturbance, dependent on the time required by the circuit breaker to open the circuit after the disturbance has started, are assumed.

If the oil circuit breaker is located at some other point in the system with considerable line or transformer impedance between the generating apparatus and circuit breaker, allowance must be made for the current-limiting effect of this additional impedance. Instead of the generated kilowatt capacity, an equivalent kilowatt capacity must be used, which refers to the actual location of the circuit breaker in the system and is lower than generated kilowatt capacity, by an amount dependent on the characteristics of the intervening conductors and circuits.

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The physical dimensions of the conducting copper parts of the circuit breaker should always carefully be considered. Conducting parts must be of sufficient size to carry the rated current indefinitely without objectionable temperature rise, also be large and strong enough for the maximum current rushes between the instant of short circuit and the time of opening of the circuit.

The use of current-limiting reactors, or reactances in transformers and machines in connection with systems is increasing. The reactor may be in circuit permanently or only when the breaker is opening. Various means have been developed to insert reactors or resistance into the circuit as the circuit breaker opens. While such arrangements reduce the current which the circuit breaker opens, they cannot act quickly enough to reduce the instantaneous maximum current and the shock on the system which is the real point to be considered.

Finally, one man will require the circuit breaker to open the most severe short circuits without the slightest indication of distress. Another man may be well pleased if the circuit breaker protects his more costly machinery, even if the circuit breaker itself is destroyed in doing so. Some one else may expect the circuit breaker to open two or possibly three times without requiring inspection or repair.

It is thus evident that there is a wide range of opinion as to what constitutes satisfactory operation; but as experience and information accumulates, this situation will gradually improve and we will approach closer to, and it is hoped will ultimately reach, the solution of the problem.

To sum up—I am in favor of rating circuit breakers on the basis of current in the arc and operating voltage of the system. The term "current in the arc" implies, that in defining its value all factors have been considered, which are necessary to determine the actual work to be performed at the time when, and at the place where, the current is interrupted.

I am not in favor of giving ratings to circuit breakers, in transient peak values which do not exist at the time of opening the circuit

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PROCEEDINGS

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

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STANDARDIZATION RULES

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Approved by the Board of Directors, June 28, 1916

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SCOPE OF THE 1916 REVISION

This edition of the Standardization Rules does not differ radically from that of the edition of July 1st, 1915, although a number of changes, deletions and additions have been made.

The sections in which changes other than minor typographical corrections have been made are as follows: **57, 58, 100, 114, 115, 131** (footnote,) **225,** to **232** (renumbered **225** to **236**), **266, 275, 276** (footnote), **283, 285, 303, 307, 312, 320, 340, 342** (renumbered **305A**), **348** (including foot-note), **350, 375** (Table III) **379, 390, 406, 321, 422, 430, 432, 436, 440** to **445, 452, 459, 470, 471, 507, 508, 540, 562, 587, 600** to **610** (renumbered **600** to **611**), **653** to **655, 679, 692, 800** (foot-note), **1000, 1003, 1006** to **1008, 1011** to **1014, 1019, 1020, 1024, 1026** to **1028, 1108, 1110.**

The following sections have been deleted: **424, 453, 623** to **630, 859, 861, 862, 865, 896, 1021** to **1023, 1025, 1029.**

The following new sections have been added: **386A, 387A, 485A, 510A, 657, 835** to **839.**

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PREFACE

In framing these rules, the chief purpose has been to define the terms and conditions which characterize the rating and behavior of electrical apparatus, with special reference to the conditions of acceptance tests.

It has not been the purpose of the rules to standardize the dimensions or details of construction of any apparatus, lest the progress of design and production should be hampered.

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STANDARDIZATION RULES

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

HISTORY OF THE STANDARDIZATION RULES

The first step taken by the Institute toward the standardization of electrical apparatus and methods was a topical discussion on "The Standardization of Generators, Motors and Transformers," which took place simultaneously in New York and Chicago on the evening of January 26, 1898. The discussion appears in the Institute TRANSACTIONS, Vol. XV, pages 3 to 32. The opinions expressed were generally favorable to the scheme of standardization of electrical apparatus, although some members feared that difficulties might arise. As a result of this discussion, a Committee on Standardization was appointed by the Council of the Institute, consisting of the following members:

FRANCIS B. CROCKER, *Chairman.*

CARY T. HUTCHINSON	CHARLES P. STEINMETZ
ARTHUR E. KENNELLY	LEWIS B. STILLWELL
JOHN W. LIEB, JR.	ELIHU THOMSON

After a careful consideration of the matter and consultation with the members of the Institute and interested parties generally, a "Report of the Committee on Standardization," was presented and accepted by the Institute, June 26, 1899. Those original rules appeared in the Institute TRANSACTIONS, Vol. XVI, pages 255 to 268.

As a result of changes and developments in the electric art, it was subsequently found necessary to revise the original report, this work being carried out by the following Committe on Standardization:

FRANCIS B. CROCKER, *Chairman.*

ARTHUR E. KENNELLY	CHARLES P. STEINMETZ
JOHN W. LIEB, JR.	LEWIS B. STILLWELL
C. O. MAILLOUX	ELIHU THOMSON

This revised report was adopted at the 19th Annual Convention at Great Barrington, Mass., on June 20, 1902, and appears in the Institute TRANSACTIONS, Vol. XIX, pages 1075 to 1092.

In consequence of still further change and development in electrical apparatus and methods, it was decided in September, 1905, that a second revision was needed, and the following Committee was appointed to do this work.

FRANCIS B. CROCKER, *Chairman.*
ARTHUR E. KENNELLY, *Secretary.*

HENRY S. CARHART	CHARLES F. SCOTT
JOHN W. LIEB, JR.	CHARLES P. STEINMETZ
C. O. MAILLOUX	HENRY G. STOTT
ROBERT B. OWENS	S. W. STRATTON

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This Committee held monthly meetings and carried on extensive correspondence with manufacturers, consulting and operating engineers and other interested parties, and as a result, presented its report at the 23d Annual Convention, held at Milwaukee, May 28–30, 1906. After considerable discussion the report was accepted and referred back to the Committee for amendment and rearrangement in form. It was then to be submitted to the Board of Directors for final adoption. In September, 1906, the following Standardization Committee was appointed:

FRANCIS B. CROCKER, *Chairman.*
ARTHUR E. KENNELLY, *Secretary.*

A. W. BERRESFORD	CHARLES F. SCOTT
DUGALD C. JACKSON	CHARLES P. STEINMETZ
C. O. MAILLOUX	HENRY G. STOTT
ROBERT B. OWENS	S. W. STRATTON

ELIHU THOMSON

This Committee held monthly meetings, also sub-committee meetings, and carefully referred the rules as a whole, and each part of them, to the members of the Institute. The rules were also entirely rearranged as to form, and put in shape to facilitate ready reference to them and enable future revisions to be made without breaking up the logical arrangement. Thus amended the rules were submitted to the Board of Directors and approved by it on June 21, 1907. The Board also directed that the rules should be presented, as accepted by the Board, at the Annual Convention held at Niagara Falls, June 24 to 27, 1907, which action was taken by President Sheldon on June 26, 1907. By the Constitution which went into effect on June 10, 1907, this Committee has been made a standing Committee with the title " Standards Committee," consisting of nine members.

On August 12, 1910, the Board of Directors increased the size of the committee from nine to twelve members; on October 14 from twelve to fourteen, and on March 10, 1911, from fourteen to sixteen. The committee thus constituted is given below.

COMFORT A. ADAMS, *Chairman.*
ARTHUR E. KENNELLY, *Secretary.*

H. W. BUCK	W. S. MOODY
GANO DUNN	R. A. PHILIP
H. W. FISHER	W. H. POWELL
H. B. GEAR	CHARLES ROBBINS
J. P. JACKSON	E. B. ROSA
W. L. MERRILL	CHARLES P. STEINMETZ
RALPH D. MERSHON	CALVERT TOWNLEY

This committee and several sub-committees held numerous meetings at which the general revision of the Standardization Rules of the Institute was considered. The complete Standardization Rules, as revised by this committee, were presented to and approved by the Board of Directors on June 27, 1911, at the Annual Convention held at Chicago, Ill.

During the following two years (1911-1913) the Standards Committee, somewhat modified and enlarged, undertook a radical revision of the Rules, particularly in connection with the important subject of Rating. In August 1913 the Committee was still further enlarged by the Board of Directors in order to permit of comprehensive sub-committees for the various parts of the work. The Committee thus constituted is given as follows:

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A. E. KENNELLY, *Chairman.*
COMFORT A. ADAMS, *Secretary.*

SUB-COMMITTEE No. 1. ON RATING.

H. M. HOBART, *Chairman.*

JAMES BURKE	W. H. POWELL
W. C. L. EGLIN	CHARLES ROBBINS
B. G. LAMME	C. F. SCOTT
W. A. LAYMAN	JAMES M. SMITH
W. L. MERRILL	CHARLES P. STEINMETZ
W. S. MOODY	J. FRANKLIN STEVENS

PHILIP TORCHIO

SUB-COMMITTEE No. 2. ON TELEGRAPH AND TELEPHONE STANDARDS.

F. B. JEWETT, *Chairman.*

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F. F. FOWLE	J. H. MORECROFT

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SUB-COMMITTEE No. 3. ON RAILWAY STANDARDS.

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HUGH HAZELTON*	HAROLD PENDER
E. R. HILL*	MARTIN SCHREIBER*
H. M. HOBART	N. W. STORER*

SUB-COMMITTEE No. 4. ON NOMENCLATURE AND SYMBOLS.

COMFORT A. ADAMS, *Chairman.*

LOUIS BELL	H. PENDER
DUGALD C. JACKSON	E. B. ROSA
M. G. LLOYD	A. S. MCALLISTER

R. H. MARRIOTT

SUB-COMMITTEE No. 5. ON WIRES AND CABLES.

H. W. FISHER, *Chairman.*

WALLACE CLARK	E. B. ROSA
W. A. DEL MAR	C. E. SKINNER
W. C. L. EGLIN	S. W. STRATTON

SUB-COMMITTEE NO. 6. ON RATING AND TESTING OF CONTROL APPARATUS.

L. T. ROBINSON, *Chairman.*

MORTON ARENDT	C. H. SHARP
N. A. CARLE	P. H. THOMAS

PHILIP TORCHIO

Sub-committee No. 1 had representation from the National Electric Light Association (Messrs. L. L. Elden, G. L. Knight, J. E. Kearns, and E. P. Dillon), from the Association of Edison Illuminating Companies (Mr. P. Torchio) and from the Electric Power Club (Messrs. James Burke and J. M. Smith).

Sub-committee No. 3, through Messrs. Schreiber and Del Mar, respectively, worked in collaboration with the Committees of the American Electric Railway Engineering Association, and the Association of Railway Electrical Engineers.

*Sub-committee No. 3 was a joint subcommittee of the Standards Committee and of the Railway Committee. The members opposite whose names occurs an asterisk, represented the latter committee.

The following members, although not appointed on the Standards Committee, have materially contributed to its work and have attended its meetings:

Carl J. Fechheimer, E. D. Priest, R. B. Williamson, K. A. Pauly, L. F. Blume, C. Renshaw, G. H. Hill, C. J. Hixson.

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The radical revision begun in 1911 was completed by this Committee and approved by the Board of Directors at a special meeting held on July 10, 1914, subject to editorial revision by the Committee, and to go into force on Dec. 1, 1914.

The Committee of 1914-1915 which carried out the editorial revision, found it impossible to complete the work satisfactorily by Dec. 1st. The edition of July 1st, 1915, approved by the Board of Directors at its meeting of June 30, 1915, thus represents substantially the completion and clarification of the previous radical revision, although it includes a number of important additions. This Committee was constituted as follows:

A. E. KENNELLY, Chairman, Harvard University, Cambridge, Mass.
C. A. ADAMS, Secretary, Harvard University, Cambridge, Mass.

JAMES BURKE, Erie, Pa.	W. H. POWELL, Milwaukee, Wis.
W. A. DEL MAR, New York,	CHARLES ROBBINS, East Pittsburgh, Pa.
H. W. FISHER, Perth Amboy, N. J.	L. T. ROBINSON, Schenectady, N. Y.
G. L. KNIGHT, Brooklyn, N. Y.	E. B. ROSA, Washington, D. C.
H. M. HOBART, Schenectady, N. Y.	C. E. SKINNER, East Pittsburgh, Pa.
F. B. JEWETT, New York.	J. M. SMITH, New York.
P. JUNKERSFELD, Chicago, Ill.	H. G. STOTT, New York.
W. L. MERRILL, Schenectady, N. Y.	P. H. THOMAS, New York.

During 1915-16 a number of changes, deletions and additions were made. The 1915-16 Committee was constituted as follows:

C. A. ADAMS, Chairman, Harvard University, Cambridge, Mass.
HAROLD PENDER, Secretary, Univ. of Pennsylvania, Philadelphia, Pa.

FREDERICK BEDELL,	P. JUNKERSFELD.
L. F. BLUME,	A. E. KENNELLY,
JAMES BURKE,	G. L. KNIGHT,
N. A. CARLE,	A. S. McALLISTER,
E. J. CHENEY,	W. M. McCONAHEY,
FRANK P. COX,	W. L. MERRILL,
W. A. DEL MAR,	R. B. OWENS,
W. F. DURAND,	CHARLES ROBBINS,
H. W. FISHER,	L. T. ROBINSON,
H. M. HOBART,	E. B. ROSA,
F. B. JEWETT,	C. E. SKINNER,

H. G. STOTT.

In addition to the members of the Standards Committee, the following members of the Institute have served on one or more of the various sub-committees: J. R. C. Armstrong, H. S. Baldwin, Joseph Bijur, G. A. Burnham, W. S. Clark, L. W. Chubb, F. M. Farmer, G. M. W. Goettling, J. D. Harnden, R. E. Hellmund, C. T. Henderson, E. M. Hewlett, Guy Hill, H. D. James, Paul MacGahan, J. N. Mahoney, H. S. Osborne, K. A. Pauly, C. H. Sharp, T. H. Schoepf, P. H. Thomas, Philip Torchio, M. O. Troy, J. L. Woodbridge.

The following societies, through the committees named, have given helpful cooperation in the present revision of the Rules:

American Society for Testing Materials,
Committee B-1.

Association of Edison Illuminating Companies,
Committee on Meters.

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Illuminating Engineering Society,
Committee on Nomenclature and Standards.

Electric Power Club,
Ciommittee on Engineering Recommendations; Standardization Committee.

National Electric Light Association
Committee on Meters.

Association of Railway Electrical Engineers
Committee on Wires and Cables.

American Electric Railway Engineering Association,
Committees on Equipment and Distribution.

Institute of Radio Engineers,
Committee on Standardization.

Society of Automobile Engineers,
Standards Committee

Of particular value in the present revision of the Rules has been the very cordial cooperation of the British Engineering Standards Committee, which was represented at the final meeting of the Standards Committee on May 15 and 16 by its Electrical Secretary, Mr. C. le Maistre, who came from London to New York for this express purpose. The British Engineering Standards Committee is supported by the following British Societies: The Institution of Civil Engineers, the Institution of Mechanical Engineers, The Institution of Naval Architects, The Iron and Steel Institute, The Institution of Electrical Engineers.

In order to crystalize the policy of the Standards Committee in its own activities, and in its relation to similar committees of other engineering societies, the 1915-16 Standards Committee formulated the by-laws given on the next page. These were approved by the Board of Directors June 28, 1916.

NOTE.

The Standards Committee takes this occasion to draw the attention of the membership to the value of suggestions based upon experience gained in the application of the Rules to general practise.

Any suggestions looking toward improvement in the Rules should be communicated to the Secretary of the Institute, for the guidance of the Standards Committee in the preparation of future editions.

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BY-LAWS OF THE STANDARDS COMMITTEE OF THE A. I. E. E.

In Section 55 of the Constitution the duties of the Standards Committee are stated as follows:

" The Standards Committee shall consider and investigate all matters relating to units and standards appertaining to or applicable in electrical engineering and in the allied arts and sciences. The Committee shall make reports and recommendations to the Board of Directors for action thereon."

The following by-laws are in accord with this section of the Constitution.

1 These by-laws, when approved by the Board of Directors, shall supersede all former resolutions governing the action and policy of the Standards Committee.

2 The minutes of each meeting, marked "Not for Publication," shall be sent by the Secretary to each member of the Committee. These minutes shall contain a summary of the reasons presented for and against any amendment or addition to the Standardization Rules which may be discussed at the meeting. An amendment or addition adopted by the Committee shall be marked in the minutes in a distinctive manner.

3 All amendments and additions adopted by the Committee during any fiscal year may be reconsidered by the Committee at any time, and shall be reviewed at its meeting held in May, and only those amendments and additions confirmed at this meeting shall be presented to the Board of Directors for their approval. Three-fourths of the votes of those present and voting shall be necessary for such confirmation. Any objection or change to be considered at this meeting shall be submitted in writing prior to the meeting and no action other than a vote for or against confirmation of any previous action of the Committee shall be taken at this meeting, except upon the unanimous vote of those present.

4 Amendments and additions to the Standardization Rules adopted by the Committee are not in force until approved by the Board of Directors, and may be reconsidered by the Committee at any time.

5 Cooperation is desirable between the Standards Committee of the Institute and other standards committees. To this end, a report, marked " Not For Publication," of the amendments and additions adopted at each meeting of the Committee shall be sent to those standards committees with which cooperation has been established.

6 An objection from a cooperating standards committee to an action taken by this Committee shall be considered at the next meeting of this Committee following the receipt of a written statement of this objection, provided such objection be submitted within thirty days from the date on which was mailed the report of the action to which objection is made.

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A notice from another standards committee of a pending objection shall, however, suffice for an extension of time. In the case of foreign standards committees, the time allowed for an objection to be filed may be extended at the option of this Committee.

7 A cooperating standards committee which may submit an objection to a previous action of this Committee shall be invited to send a representative to the meeting or meetings of this Committee at which such objection is scheduled for consideration.

8 Whenever a new edition of the Rules is issued, old Rules in which changes other than typographical corrections have been made, and all additions and deletions, shall be distinctively indicated.

9 Amendments and additions to these By-Laws may be made by this Committee, subject to the approval of the Board of Directors.

OTHER APPROVED STANDARDIZATION RULES

At the April meeting the Standards Committee passed the following resolution, which was approved by the Board of Directors on April 14th:

" The Standards Committee, with the approval of the Board of Directors, recommends the use of the following rules and standards as adopted by other societies. These have been formally presented to the Standards Committee by the societies concerned and are found not to be incompatible with the Standardization Rules."

The Standards Committee will be pleased to receive from any of the engineering societies such standardization rules as they may care to have included in this list. Such rules will be included (by title only) if they are found not to be incompatible with the Standardization Rules of the A. I. E. E.

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STANDARDIZATION RULES

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

DEFINITIONS

NOTE. The following definitions are intended to be practically descriptive, rather than scientifically rigid.

CURRENT, E.M.F. and POWER.

(The definitions of currents given below apply also, in most cases, to electromotive force, potential difference, magnetic flux, etc.)

1 **Direct Current.** A unidirectional current. As ordinarily used, the term designates a practically non-pulsating current.

2 **Pulsating Current.** A current which pulsates regularly in magnitude. As ordinarily employed, the term refers to unidirectional current.

3 **Continuous Current.** A practically non-pulsating direct current.

4 **Alternating Current.** A current which alternates regularly in direction. Unless distinctly otherwise specified, the term "alternating current" refers to a periodic current with successive half waves of the same shape and area.

5 **Oscillating Current.** A periodic current whose frequency is determined by the constants of the circuit or circuits.

6 **Cycle.** One complete set of positive and negative values of an alternating current.

7 **Electrical Degree.** The 360th part of a cycle.

8 **Period.** The time required for the current to pass through one cycle.

9 **Frequency.** The number of cycles or periods per second. The product of 2π by the frequency is called the *angular velocity* of the current.

10 **Root-Mean-Square** or **Effective Value.** The square root of the mean of the squares of the instantaneous values for one complete cycle. It is usually abbreviated r.m.s. Unless otherwise specified, the numerical value of an alternating current refers to its r.m.s. value. The r.m.s. value of a sinusoidal wave is equal to its maximum, or crest value, divided by $\sqrt{2}$. The word "virtual" is sometimes used in place of r.m.s., particularly in Great Britain.

11 **Wave-Form** or **Wave-Shape.** The shape of the curve obtained when the instantaneous values of an alternating current are plotted against time in rectangular co-ordinates. The distance along the time axis corresponding to one complete cycle of values is taken as 2π radians, or 360 degrees. Two alternating quantities are said to have the same wave-form when their ordinates of corresponding phase (see § 13) bear a constant ratio to each other. The wave-shape, as thus understood, is therefore independent of the frequency of the current and of the scale to which the curve is represented.

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12 **Simple Alternating** or **Sinusoidal Current.** One whose wave-shape is sinusoidal.

Alternating-current calculations are commonly based upon the assumption of sinusoidal currents and voltages.

13 **Phase.** The distance, usually in angular measure, of the base of any ordinate of an alternating wave from any chosen point on the time axis, is called the phase of this ordinate with respect to this point. In the case of a sinusoidal alternating quantity, the phase at any instant may be represented by the corresponding position of a line or *vector* revolving about a point with such an angular velocity ($\omega = 2\pi f$), that its projection at each instant upon a convenient reference line is proportional to the value of the quantity at that instant.

14 **Non-Sinusoidal Quantities.** Quantities that cannot be represented by vectors of constant length in a plane. The following definitions of phase, active component, reactive component, etc., are not in general applicable thereto. Certain "equivalent" values, as defined below, may, however, be used in many instances, for the purpose of approximate representation and calculation.

15 **Crest-Factor or Peak-Factor.** The ratio of the crest or maximum value to the r.m.s. value. The crest factor of a sine-wave is $\sqrt{2}$.

16 **Form Factor.** The ratio of the r.m.s. to the algebraic mean ordinate taken over a half-cycle beginning with the zero value. If the wave passes through zero more than twice during a single cycle, that zero shall be taken which gives the largest algebraic mean for the succeeding half-cycle. The form factor of a sine-wave is 1.11.

17 **The Distortion Factor of a wave.** The ratio of the r.m s. value of the first derivative of the wave with respect to time, to the r.m.s. value of the first derivative of the equivalent sine wave.

18 **Equivalent Sine Wave.** A sine wave which has the same frequency and the same r.m.s. value as the actual wave.

*19 **Phase Difference: Lead and Lag.** When corresponding cyclic values of two sinusoidal alternating quantities of the same frequency occur at different instants, the two quantities are said to differ in phase by the angle between their nearest corresponding values; *e.g.*, the phase angle between their nearest ascending zeros or between their nearest positive maxima. That quantity whose maximum value occurs first in time is said to lead the other, and the latter is said to lag behind the former.

*20 **Counter-Clockwise Convention.** It is recommended that in any vector diagram, the leading vector be drawn counter-clockwise with respect to the lagging vector, † as in the accompanying diagram, where OI represents the vector of a current in a simple alternating-current circuit, lagging behind the vector OE of impressed e.m.f.

*Note: Definitions 19, 20, 21, 22, 23, 24, 25 refer strictly only to cases where the voltage and current are both sinusoidal (see §11 and 12).

†See Publication of 12 the International Electrotechnical Commission (Report of Turin meeting, Sept. 1911, p. 78).

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*21 **The Active or In-Phase Component** of the current in a circuit is that component which is in phase with the voltage across the circuit; similarly the active component of the voltage across a circuit is that component which is in phase with the current. The use of the term *energy component* for this quantity is disapproved.

*22 **Reactive or Quadrature Component of the current in a circuit.** That component which is in quadrature with the voltage across the circuit; similarly, the reactive component of the voltage across the circuit is that component which is in quadrature with the current. The use of the term *wattless component* for this quantity is disapproved.

*23 **Reactive Factor.** The sine of the angular phase difference between voltage and current; *i. e.*, the ratio of the reactive current or voltage to the total current or voltage.

*24 **Reactive Volt-Amperes.** The product of the reactive component of the voltage by the total current, or of the reactive component of the current by the total voltage.

*25 **Non-Inductive Load and Inductive Load.** A *non-inductive* load is a load in which the current is in phase with the voltage across the load. An *inductive* load is a load in which the current lags behind the voltage across the load. A *condensive* or *anti-inductive* load is one in which the current leads the voltage across the load.

26 **Power in an Alternating-Current Circuit.** The average value of the products of the coincident instantaneous values of the current and voltage for a complete cycle, as indicated by a wattmeter.

27 **Volt-Amperes or Apparent Power.** The product of the r.m.s. value of the voltage across a circuit by the r.m.s. value of the current in the circuit. This is ordinarily expressed in kv-a.

28 **Power Factor.** The ratio of the power (cyclic average as defined in §26) to the volt-amperes. In the case of sinusoidal current and voltage, the power factor is equal to the cosine of their difference in phase.

29 **Equivalent Phase Difference.** When the current and e.m.f. in a given circuit are non-sinusoidal, it is customary, for purposes of calculation, to take as the "equivalent" phase difference, the angle whose cosine is the power factor (see §28) of the circuit. There are cases, however, where this equivalent phase difference is misleading, since the presence of harmonics in the voltage wave, current wave, or in both, may reduce the power factor without producing a corresponding displacement of the two wave forms with respect to each other; *e.g.*, the case of an a-c. arc. In such cases, the components of the equivalent sine waves, the equivalent reactive factor and the equivalent reactive volt-amperes may have no physical significance.

30 **Single-Phase.** A term characterizing a circuit energized by a single alternating e.m.f. Such a circuit is usually supplied through

*Note: Definitions 19, 20, 21, 22, 23, 24, 25 refer strictly only to cases where the voltage and current are both sinusoidal (see §11 and 12).

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two wires. The currents in these two wires, counted positively outwards from the source, differ in phase by 180 degrees or a half-cycle.

31 **Three-Phase.** A term characterizing the combination of three circuits energized by alternating e.m.f.'s. which differ in phase by one-third of a cycle; *i.e.*, 120 degrees.

32 **Quarter-Phase, also called Two-Phase.** A term characterizing the combination of two circuits energized by alternating e.m.f's. which differ in phase by a quarter of a cycle; *i.e.*, 90 degrees.

33 **Six-Phase.** A term characterizing the combination of six circuits energized by alternating e.m.f's. which differ in phase by one sixth of a cycle; *i.e.*, 60 degrees.

34 **Polyphase.** A general term applied to any system of more than a single phase. This term is ordinarily applied to symmetrical systems.

Per Cent Drop.

50 In electrical machinery, the ratio of the **internal resistance drop** to the terminal voltage, expressed in per cent, is called the "*per cent resistance drop.*"

51 Similarly the ratio of the **internal reactance drop** to the terminal voltage, expressed in per cent, is called the "*per cent reactance drop.*"

52 Similarly the ratio of the **internal impedance drop** to the terminal voltage, expressed in per cent, is called the "*per cent impedance drop.*"

Unless otherwise specified, these per cent drops shall be referred to rated load and rated power factor.

53 **In the case of transformers,** the per cent drop will be the sum of the primary drop (reduced to secondary turns) and the secondary drop, in per cent of secondary terminal voltage.

54 **In the case of induction motors,** it is advantageous to express the drops in per cent of the internally induced e.m.f.

55 **The Load Factor of a machine, plant or system.** The ratio of the average power to the maximum power during a certain period of time. The average power is taken over a certain period of time, such as a day, a month, or a year, and the maximum is taken as the average over a short interval of the maximum load within that period.

In each case, the interval of maximum load and the period over which the average is taken should be definitely specified, such as a "half-hour monthly" load-factor. The proper interval and period are usually dependent upon local conditions and upon the purpose for which the load factor is to be used.

56 **Plant Factor.** The ratio of the average load to the rated capacity of the power plant, *i.e.*, to the aggregate ratings of the generators.

57 **The Demand of an Installation or System** is the load which is drawn from the source of supply at the receiving terminals averaged over a suitable and specified interval of time. Demand is expressed in kilowatts, kilovolt-amperes, amperes, or other suitable units.

58 **The Maximum Demand of an Installation or System** is the greatest of all the demands which have occurred during a given period.

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It is determined by measurement, according to specifications, over a prescribed time interval.

59 **Demand Factor.** The ratio of the maximum demand of any system or part of a system, to the total connected load of the system, or of the part of system, under consideration.

60 **Diversity Factor.** The ratio of the sum of the maximum power demands of the subdivisions of any system or parts of a system to the maximum demand of the whole system or of the part of the system under consideration, measured at the point of supply.

61 **Connected Load.** The combined continuous rating of all the receiving apparatus on consumers' premises, connected to the system or part of the system under consideration.

62 **The Saturation Factor of a machine.** The ratio of a small percentage increase in field excitation to the corresponding percentage increase in voltage thereby produced. Unless otherwise specified, the saturation factor of a machine refers to the no-load excitation required at normal rated speed and voltage. It is determined from measurements of saturation made on open circuit at rated speed.

63 **The Percentage Saturation** of a machine at any excitation may be found from its saturation curve of generated voltage as ordinates, against excitation as abscissas, by drawing a tangent to the curve at the ordinate corresponding to the assigned excitation, and extending the tangent to intercept the axis of ordinates drawn through the origin. The ratio of the intercept on this axis to the ordinate at the assigned excitation, when expressed in percentage, is the percentage of saturation and is independent of the scales selected for excitation and voltage. This ratio, as a fraction, is equal to the reciprocal of the saturation-factor at the same excitation, deducted from unity; or, if f be the saturation factor and p the percentage of saturation,

$$p = 100\left(1 - \frac{1}{f}\right).$$

64 **Magnetic Degree.** The 360th part of the angle subtended, at the axis of a machine, by a pair of its field poles. One **mechanical degree** is thus equal to as many magnetic degrees as there are pairs of poles in the machine.

65 **The Variation in Prime Movers** which do not give an absolutely uniform rate of rotation or speed, as in reciprocating steam engines, is the maximum angular displacement in position of the revolving member expressed in degrees, from the position it would occupy with uniform rotation, and with one revolution taken as 360 degrees.

66 **The Variation in Alternators** or alternating-current circuits in general, is the maximum angular displacement, expressed in electrical degrees, (one cycle = 360 deg.) of corresponding ordinates of the voltage wave and of a wave of absolutely constant frequency equal to the average frequency of the alternator or circuit in question, and may be due to the variation of the prime mover.

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67 **Relations of Variations in Prime Mover and Alternator.** If p is the number of pairs of poles, the variation of an alternator is p times the variation of its prime mover, if direct-connected, and pn times the variation of the prime mover if rigidly connected thereto in such a manner that the angular speed of the alternator is n times that of the prime mover.

68 **The Pulsation in Prime Movers, or in the alternator connected thereto.** The ratio of the difference between the maximum and minimum velocities in an engine-cycle to the average velocity.

80 **Capacity.** The two different senses in which this word is used sometimes lead to ambiguity. It is therefore recommended that whenever such ambiguity is likely to arise, the descriptive term *power capacity* or *current capacity* be used, when referring to the power or current which a device can safely carry, and that the term "*Capacitance*" be used when referring to the electrostatic capacity of a device.

81 **Resistor.** A device, heretofore commonly known as a resistance, used for the operation, protection, or control of a circuit or circuits. See § 740.

82 **Reactor.** A coil, winding or conductor, heretofore commonly known as a reactance coil or choke coil, possessing inductance, the reactance of which is used for the operation, protection or control of a circuit or circuits. See also § 214 and 736.

83 **Efficiency.** The efficiency of an electrical machine or apparatus is the ratio of its useful output to its total input.

TABLE I.

90 **Symbols and Abbreviations.**

Name of Quantity.	Symbol for the Quantity.	Unit.	Abbreviation for the Unit.
Electromotive force, abbreviated e.m.f.	E, e	volt	....
Potential difference, abbreviated p.d.	V, v or E, e	"	....
Voltage	E, e or V, v	"	....
Current	I, i	ampere	....
Quantity of electricity	Q, q	coulomb, ampere-hour	....
Power	P, p	watt	....
Electrostatic flux	Ψ	....	....
Electrostatic flux density	D	....	....
Electrostatic field intensity	F		
Magnetic flux	Φ, φ	maxwell*	....
Magnetic flux density	$B, \mathfrak{B}$	gauss*	....
Magnetic field intensity	$H, \mathfrak{H}$	gilbert per centimeter or gauss†	gilbert per cm. ....

*An additional unit for m. m. f. is the "ampere-turn," for flux the "line," for magnetic flux-density "maxwells per sq. in."

†The gauss is provisionally accepted for the present as the name of both the unit of field intensity and flux density, on the assumption that permeability is a simple numeric.

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Magnetomotive force, abbreviated m.m.f.	$\mathfrak{F}$	gilbert*	....
Intensity of magnetization.	J	....	....
Susceptibility	$\kappa = J/H$	....	....
Permeability	$\mu = B/H$	....	....
Resistance	R, r	ohm	....
Reactance	X, x	"	....
Impedance	Z, z	"	....
Conductance	g	mho	....
Susceptance	b	"	....
Admittance	Y, y	"	....
Resistivity	ρ	*ohm-centimeter	ohm-cm.
Conductivity	γ	*mho per centimeter	mho per cm.
Dielectric constant	ϵ or k	....	....
Reluctance	$\mathfrak{R}$	....	....
Capacitance (Electrostatic capacity)	C	farad	....
Inductance (or coefficient of self induction)	L	henry	....
Mutual Inductance (or coefficient of mutual induction)	M	henry	....
Phase displacement	θ, φ	degree or radian	•
Frequency	f	cycle per second	~
Angular velocity	ω	radian per second	....
Velocity of rotation	n	revolution per second	rev. per sec.
Number of conductors or turns	N	convolution or turns of wire	
Temperature	T, t, θ	degree centigrade	°C.
Energy, in general	U or W	joule, watt-hour	....
Mechanical work	W or A	joule, watt-hour	....
Efficiency	η	per cent	....
Length	l	centimeter	cm.
Mass	m	gram	g.
Time	t	second	sec.

*Note. The numerical values of these quantities are *ohms resistance* and *mhos conductance* between two opposite faces of a cm. cube of the material in question, but the correct names are as given, not ohms and ohms per cm. cube, as commonly stated.

†This has been the accepted standard value for many years and was formerly considered to correspond accurately to 45° Latitude and sea level. Later researches, however, have shown that the most reliable value for 45° and sea-level is slightly different; but this does not affect the standard value given above.

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Acceleration due to gravity	g	centimeter per second per second	cm. per sec. per sec.
Standard acceleration due to gravity (at about 45 deg. latitude and sea level) equals 980.665†	g_o	centimeter per second per second	cm. per sec. per sec.

91 E_m, I_m and P_m should be used for maximum cyclic values, e, i and p for instantaneous values, E and I for r.m.s. values (see §10) and P for the average value of the power, or the active power. These distinctions are not necessary in dealing with continuous-current circuits. In print, vector quantities should be represented by boldface capitals.

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CLASSIFICATION OF MACHINERY

100 The machinery under consideration in these rules may be classified in various ways, these various classifications overlapping or interlocking in considerable degree. Briefly, they are Direct-Current or Alternating-Current, Rotating or Stationary. Under Rotating Apparatus there are two principal classifications: *First*, according to the function of the machines; Motors, Generators. Boosters, Motor-Generators, Dynamotors, Double-Current Generators, Converters and Phase Advancers; *Second*, according to the type of construction or principle of operation; Commutating, Synchronous, Induction, Unipolar, Rectifying. Obviously, some of these machines could be rationally included in either classification, *e.g.*, Motor-Generators and Rectifying Machines.

In the following, self-evident definitions have for the most part, been omitted.

ROTATING MACHINES.

FUNCTIONAL CLASSIFICATION OF ROTATING MACHINES.

101 **Generator.** A machine which transforms mechanical power into electrical power.

102 **Motor.** A machine which transforms electrical power into mechanical power.

103 **Booster.** A generator inserted in series in a circuit to change its voltage. It may be driven by an electric motor (in which case it is termed a motor-booster) or otherwise.

104 **Motor-Generator Set.** A transforming device consisting of a motor mechanically coupled to one or more generators.

105 **Dynamotor.** A transforming device combining both motor and generator action in one magnetic field, either with two armatures, or with one armature having two separate windings and independent commutators.

106 **A Direct-Current Compensator** or **Balancer** comprises two or more similar direct-current machines (usually with shunt or compound excitation) directly coupled to each other and connected in series across the outer conductors of a multiple-wire system of distribution, for the purpose of maintaining the potentials of the intermediate wires of the system, which are connected to the junction points between the machines.

107 **A Double-Current Generator** supplies both direct and alternating currents from the same armature-winding.

108 **A Converter** is a machine employing mechanical rotation in changing electrical energy from one form into another. There are several types of converters as follow:

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109 **A Direct-Current Converter** converts from a direct current to a direct current, usually with a change of voltage. Such a machine may be either a motor-generator set or a dynamotor.

110 **A Synchronous Converter** (sometimes called a Rotary Converter) converts from an alternating to a direct current, or vice-versa. It is a synchronous machine with a single closed-coil armature winding, a commutator and slip rings.

111 **A Cascade Converter,** also called a **Motor Converter,** is a combination of an induction motor with a synchronous converter, the secondary circuit of the former feeding directly into the armature of the latter; *i.e.*, it is a synchronous converter concatenated with an induction motor.

112 **A Frequency Converter** converts the power of an alternating-current system from one frequency to another, with or without a change in the number of phases, or in the voltage.

113 **A Rotary Phase-Converter** converts from an alternating-current system of one or more phases to an alternating-current system of a different number of phases, but of the same frequency.

114 **A Phase Advancer** is a machine which supplies reactive volt-amperes to the system to which it is connected. Phase advancers may be either synchronous or asynchronous.

115 **A Synchronous Condenser** or **Synchronous Phase Advancer** is a synchronous machine, running either idle or with load, the field excitation of which may be varied so as to modify the power-factor of the system, or through such modification to influence the load voltage. The function of a synchronous condenser is to supply reactive volt-amperes to the system with which it is connected.

CONSTRUCTIONAL CLASSIFICATION OF ROTATING MACHINES

Commutating Machines

130 **Direct-Current Commutating Machines** comprise a magnetic field of constant polarity, an armature, and a commutator connected therewith. These include: Direct-Current Generators; Direct-Current Motors; Direct-Current Boosters; Direct-Current Motor-Generator Sets and Dynamotors; Direct-Current Compensators or Balancers; and Arc Machines.

131 **Alternating-Current Commutating Machines*** comprise a magnetic field of alternating polarity, an armature, and commutator connected therewith.

132 **Synchronous Commutating Machines** include synchronous converters, cascade-converters, and double-current generators.

133 **Synchronous Machines** comprise a constant magnetic field and an armature receiving or delivering alternating-currents in

*A suggested classification of alternating current commutator motors is given in the July 1916 PROCEEDINGS of the Institute.

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synchronism with the motion of the machine; *i.e.*, having a frequency strictly proportional to the speed of the machine. They may be sub-divided as follow:

134 **An Alternator** is a synchronous alternating-current generator, either single-phase or polyphase.

135 **A Polyphase Alternator** is a polyphase synchronous alternating-current generator, as distinguished from **a singlephase alternator.**

136 **An Inductor Alternator is an Alternator** in which both field and armature windings are stationary, and in which masses of iron or inductors, by moving past the coils, alter the magnetic flux through them. It may be either single-phase or polyphase.

137 **A Synchronous Motor** is a machine structurally identical with an alternator, but operated as a motor.

138 **Induction Machines** include apparatus wherein primary and secondary windings rotate with respect to each other; *i.e.*, induction motors, induction generators, certain types of frequency converters and certain types of rotary phase-converters.

139 **An Induction Motor** is an alternating-current motor, either singlephase or polyphase, comprising independent primary and secondary windings, one of which, usually the secondary, is on the rotating member. The secondary winding receives power from the primary by electromagnetic induction.

140 **An Induction Generator** is a machine structurally identical with an induction motor, but driven above synchronous speed as an alternating-current generator.

141 **Unipolar or Acyclic Machines** are direct-current machines, in which the voltage generated in the active conductors maintains the same direction with respect to those conductors.

SPEED CLASSIFICATION OF MOTORS.

150 **Motors** may, for convenience, be classified with reference to their speed characteristics as follow:

151 **Constant-Speed Motors,** whose speed is either constant or does not materially vary; such as synchronous motors, induction motors with small slip, and ordinary direct-current shunt motors.

152 **Multispeed Motors** two-speed, three-speed. etc.), which can be operated at any one of several distinct speeds, these speeds being practically independent of the load; such as motors with two armature windings, or induction motors in which the number of poles is changed by external means.

153 **Adjustable-Speed Motors,** in which the speed can be varied gradually over a considerable range, but when once adjusted remains practically unaffected by the load, such as shunt motors designed for a considerable range of speed variation.

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154 **Varying-Speed Motors,** or motors in which the speed varies with the load, ordinarily decreasing when the load increases; such as series motors, compound-wound motors, and series-shunt motors. As a sub-class of varying-speed motors, may be cited, **adjustable varying-speed motors,** or motors in which the speed can be varied over a considerable range at any given load, but when once adjusted, varies with the load; such as compound-wound motors arranged for adjustment of speed by varying the strength of the shunt field

CLASSIFICATION OF ROTATING MACHINES RELATIVE TO THE DEGREE OF ENCLOSURE OR PROTECTION

160 The following types are recognized:

Open
Protected
Semi-enclosed
Enclosed
Separately ventilated
Water-cooled
Self-ventilated
Drip-proof
Moisture-resisting
Submersible
Explosion-proof
Explosion-proof slip-ring enclosure

161 **An "open" machine** is of either the pedestal-bearing or end-bracket type where there is no restriction to ventilation, other than that necessitated by good mechanical construction.

162 **A "protected" machine** is one in which the armature, field coils, and other live parts are protected mechanically from accidental or careless contact, while free ventilation is not materially obstructed.

163 **A "semi-enclosed" machine** is one in which the ventilating openings in the frame are protected with wire screen, expanded metal, or other suitable perforated covers, having apertures not exceeding ½ of a square inch (3.2 sq. cm.) in area.

164 **An "enclosed" machine** is so completely enclosed by integral or auxiliary covers as to prevent a circulation of air between the inside and outside of its case, but not sufficiently to be termed air-tight.

165 A **"separately ventilated" machine** has its ventilating air supplied by an independent fan or blower external to the machine.

166 A **"water-cooled" machine** is one which mainly depends on water circulation for the removal of its heat.

167 A **"self-ventilated" machine** differs from a separately ventilated machine only in having its ventilating air circulated by a fan, blower, or centrifugal device integral with the machine.

If the heated air expelled from the machine is conveyed away through a pipe attached to the machine, this should be so stated.

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168 **A "drip-proof" machine** is one so protected as to exclude falling moisture or dirt. A "drip proof" machine may be either "open" or "semi-enclosed", if it is provided with suitable protection integral with the machine, or so enclosed as to exclude effectively falling solid or liquid material.

169 A **moisture-resisting machine** is one in which all parts are treated with moisture-resisting material. Such a machine shall be capable of operating continuously or intermittently in a very humid atmosphere, such as in mines, evaporating rooms, etc.

170 **A "submersible" machine** is a machine capable of withstanding complete submersion, in fresh water or sea water, as may be specified, for four hours without injury.

171 **An "explosion-proof" machine** is a machine in which the enclosing case can withstand, without injury, any explosion of gas that may occur within it, and will not transmit the flame to any inflammable gas outside it.

172 An induction motor in which the slip rings and brushes alone are included within an explosion-proof case should not be described as an explosion-proof machine, but as a machine "with **explosion-proof slip-ring enclosure.**"

STATIONARY INDUCTION APPARATUS

200 **Stationary Induction Apparatus** changes electric energy to electric energy, through the medium of magnetic energy, without mechanical motion. It comprises several forms, distinguished as follow:

201 **Transformers**, in which the primary and secondary windings are ordinarily insulated one from another.

202 The terms **"high-voltage"** and **"low-voltage"** are used to distinguish the winding having the greater from that having the lesser number of turns. The terms **"primary"** and **"secondary"** serve to distinguish the windings in regard to energy flow, the primary being that which receives the energy from the supply circuit, and the secondary that which receives the energy by induction from the primary.

203 The **rated current of a constant-potential transformer is** that secondary current which, multiplied by the rated-load secondary voltage, gives the kv-a. rated output. That is, a transformer of given kv-a. rating must be capable of delivering the rated output at rated secondary voltage, while the primary impressed voltage is increased to whatever value is necessary to give rated secondary voltage.

The **Rated Primary Voltage** of a constant-potential transformer is the rated secondary voltage multiplied by the turn ratio.

204 The **ratio of a transformer,** unless otherwise specified, shall be the ratio of the number of turns in the high-voltage winding to that in the low-voltage winding; *i.e.*, the **"turn-ratio"**

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205 The **voltage ratio** of a transformer is the ratio of the r.m.s. primary terminal voltage to the r.m.s. secondary terminal voltage, under specified conditions of load.

206 The **" current ratio "** of a current-transformer is the ratio of r.m.s. primary current to r.m.s. secondary current, under specified conditions of load.

207 The **" marked ratio "** of an instrument transformer is the ratio which the apparatus is designed to give under average conditions of use. When a precise ratio is required, it is necessary to specify the voltage, frequency, load and power factor of the load.

208 **Volt-Ampere Ratio of Transformers.**

The volt-ampere ratio, which should not be confused with real efficiency, is the ratio of the volt-ampere output to the volt-ampere input of a transformer, at any given power factor.

209 **Auto-transformers** have a part of their turns common to both primary and secondary circuits.

210 **Voltage Regulators** have turns in shunt and turns in series with the circuit, so arranged that the voltage ratio of the transformation or the phase relation between the circuit-voltages is variable at will. They are of the following three classes:

211 **Contact Voltage Regulators,** in which the number of turns in one or both of the coils is adjustable.

212 **Induction Voltage Regulators,** in which the relative positions of the primary and secondary coils are adjustable.

213 **Magneto Voltage Regulators,** in which the direction of the magnetic flux with respect to the coils is adjustable.

214 **Reactors,** heretofore commonly called **Reactance-Coils,** also called **Choke Coils**; a form of stationary induction apparatus used to supply reactance or to produce phase displacement. See also **§82** and **736.**

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METERS AND INSTRUMENTS

225 Although the terms **Instruments** and **Meters** are frequently used synonymously in referring to electrical measuring devices, the meter departments of manufacturing and operating companies commonly use the word "meters" in the collective sense to designate only those devices which register the total energy or quantity of electricity consumed in or supplied to a circuit, and reserve the term "instruments," in the collective sense, for all other electrical measuring or indicating devices.

226 In general, the names of meters and instruments are self-defining, particularly when considered in connection with existing definitions. The following terms are preferred to other terms sometimes used for the same devices: **Reactive-Factor Meter, Power-Factor Meter, Watt-hour Meter,** etc.

227 **Crest Voltmeter.** A voltmeter depending for its indications upon the crest, that is the maximum value of the voltage of the system to which it is connected. The instruments are so calibrated that they indicate the r. m. s. value of the sinusoidal voltage having the same crest value.

228 **Synchronoscope** (also called a Synchroscope or Synchronism Indicator). A device which in addition to indicating synchronism between two machines, shows whether the speed of the incoming machine is fast or slow.

229 **Reactive-Volt-Ammeter** (also called a Reactive-Volt-Ampere Indicator). An instrument which indicates the reactive volt-amperes of the circuit to which it is connected.

230 **Line Drop Voltmeter Compensator.** A device used in connection with a voltmeter which causes it to indicate the voltage at some distant point of the circuit.

231 **Recording Ammeters, Voltmeters, Wattmeters, etc.,** are instruments which record graphically upon time-charts the values of the quantities they measure.

232 **A Demand Meter** is a device which indicates or records the demand or maximum demand (See §§**57** and **58**). In practice two types are recognized:

233 **An Integrated-Demand Meter** is one which indicates or records the maximum demand obtained through integration.

234 **A Lagged-Demand Meter** is one in which the indication of maximum demand is subject to a characteristic time lag.

235 **Errors of Indicating Instruments.** In specifying the accuracy of an indicating instrument, the error at any point on the scale shall be expressed as a percentage of the full scale reading.

236 **Torque** of meters and instruments shall be expressed in **milli-meter-grams.**

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STANDARDS FOR ELECTRICAL MACHINERY

250 *The expressions " machinery " and " machines " are here employed in a general sense, in order to obviate the constant repetition of the words " machinery or induction apparatus."*

251 *All temperatures are to be understood as centigrade.*

252 *The expression " capacity " is to be understood as indicating " capability ", except where specifically qualified, as, for instance, in the case of allusions to electrostatic capacity, i. e., capacitance.*

253 *Wherever special rules are given for any particular type of machinery or apparatus (such as switches, railway motors, railway substation machinery, etc., these special rules shall be followed, notwithstanding any apparent conflict with the provisions of the more general sections. In the absence of special rules on any particular point, the general rules on this point shall be followed.*

260 **Objects of Standardization.** To ensure satisfactory results, electrical machinery should be specified to conform to the Institute Standardization Rules, in order that it shall comply, in operation, with approved limitations in the following respects, so far as they are applicable.

Operating temperature
Mechanical strength
Commutation
Dielectric strength
Insulation resistance
Efficiency
Power factor
Wave shape
Regulation

261 **Capacity or Available Output of an Electrical Machine.** So far as relates to the purposes of these Standardization Rules, the Institute defines the Capacity of an Electrical Machine as the load which it is capable of carrying for a specified time (or continuously), without exceeding in any respect the limitations herein set forth.

Except where otherwise specified, the capacity of an electrical machine shall be expressed in terms of its available *output*. For exceptions see §277 and 802.

262 **Rating of an Electrical Machine.** Capacity should be distinguished from Rating. The Rating of a machine is the output marked on the Rating Plate, and shall be based on, but shall not exceed, the maximum* load which can be taken from the machine under prescribed conditions of test. This is also called the rated output.

*The term "maximum Load" does not refer to loads applied solely for mechanical commutation, or similar tests.

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263 **The Principle upon which Machine Ratings** are based, so far as relates to thermal characteristics, is that the rated load, applied continuously or for a stated period, shall produce a temperature rise which, superimposed upon a standard ambient temperature, will not exceed the maximum safe operating temperature of the insulation.

264 **A. I. E. E. and I. E. C. Ratings.** When the prescribed conditions of test are those of the A. I. E. E. Standardization Rules, the rating of the machine is the Institute Rating. (See **§620**). When the prescribed conditions of the test are those of the I. E. C.† Rules, the rating of the machine is the I. E. C. rating. A machine so rated in either case may bear a distinctive sign upon its rating plate.

265 **Standard Temperature and Barometric Pressure for Institute Rating.** The Institute Rating (See **§262**) of a machine shall be its capacity when operating with a cooling medium of the ambient temperature of reference (40° for air or 25° for water, see **§305** and **309**) and with barometric conditions within the range given in **§308**. See **§§305A, 307, 320** and **321.**

266 **The Temperature Rises Specified in these Rules** apply to all ambient temperatures up to and including, but not exceeding, 40°C. for air and 25 C. for water. (For definition of ambient temperature see **§303**.)

267 **Any Machinery Destined for Use with Higher Ambient** tempera tures of cooling mediums, and also any machinery for operation at altitudes for which no provision is made in **§308**, should be the subject of special guarantee by the manufacturer. The methods of test and performance set forth in these Rules will, however, afford guidance in such cases.

UNITS IN WHICH RATING SHALL BE EXPRESSED

274 The rating of **Direct-Current Generators,** shall be expressed in kilowatts (kw.) available at the terminals.

275 The rating of **Alternators** and **Transformers,** shall be expressed in kilovolt-amperes (kv-a.) available at the output terminals, at a specified power factor.

276 It is strongly recommended that the **rating of motors** shall be expressed in kilowatts* (kw.) available at the shaft. (An ex-

†I.E.C. stands for "International Electrotechnical Commission. This rating has not yet been established.

*Since the input of machinery of this class is measured in electrical units and since the output has a definite relation to the input, it is logical and desirable to measure the delivered power in the same units as are employed for the received power. Therefore, the output of motors should be expressed in kilowatts instead of in horse power. However, on account of the hitherto prevailing practice of expressing mechanical output in horse power, it is recommended that for machinery of this class the rating should, for the present, be expressed both in kilowatts and in horse power; as follows:

kw.————approx. equiv. h.p.————

For the purposes of these Rules the horse-power shall be taken as 746.0 watts.

In order to lay stress upon the preferred future basis, it is desirable that on Rating plates, the Rating in kilowatts shall be shown in larger and more prominent characters than the rating in horse power.

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ception to this rule is made in the case of Railway motors, which, for some purposes, are also rated by their *input*, see §802.)

277 **Auxiliary machinery,** such as regulators, resistors, reactors, balancer sets, stationary and synchronous condensers, etc., shall have their ratings appropriately expressed. It is essential to specify also the voltage (and frequency, if a-c.,), of the circuits on which the machinery may appropriately be used.

KINDS OF RATING

There are various kinds of rating such as:

281 **Continuous Rating.** A machine rated for continuous service shall be able to operate continuously at its rated output, without exceeding any of the limitations referred to in §260.

282 **Short-Time Rating.** A machine rated for short-time service; (*i.e.* service including runs alternating with stops of sufficient duration to ensure substantial cooling), shall be able to operate at its rated output during a limited period, to be specified in each case, without exceeding any of the limitations referred to in §260. Such a rating is a **short-time rating.**

283 **Nominal Ratings.** For railway motors and sometimes for railway substation machinery, certain nominal ratings are employed. See §§765 and 800. Nominal ratings for automobile propulsion motors and generators are not recommended; see §837.

284 **Duty-Cycle Operation.** Many machines are operated on a cycle of duty which repeats itself with more or less regularity. For purposes of rating, either a continuous or a short-time equivalent load, may be selected, which shall simulate as nearly as possible the thermal conditions of the actual duty cycle.

285 **Standard durations of equivalent tests** shall be for machines operating under specified duty-cycles as follow (see also §836):

5 minutes
10 "
15 "
30 "
60 "
120 "
and continuous.

Of these the first six are short-time ratings, selected as being thermally equivalent to the specified duty cycle.

When, for example, a short-time rating of 10 minutes duration is adopted, and the thermally equivalent load is 25 kw. for that period, then such a machine shall be stated to have a 10-minute rating of 25 kw.

286 In every case the equivalent short-time test shall commence only when the windings and other parts of the machine are **within 5°C of the ambient temperature** at the time of starting the test.

287 In the absence of any specification as to the kind of rating, the continuous rating shall be understood.*

*An exception is made in the case of motors for railway service, where in the absence of any specification as to the kind of rating, the "**nominal rating**" as defined in §319 and 415 shall be understood.

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288 Machines marked in accordance with **§264** shall be understood to have a continuous rating, unless otherwise marked in accordance with **§285**.

HEATING AND TEMPERATURE

300 **Temperature Limitations of the Capacity of Electrical Machinery.** The capacity, so far as relates to temperature, is usually limited by the maximum temperature at which the materials in the machine, especially those employed for insulation, may be operated for long periods without deterioration. When the safe limits are exceeded, deterioration is rapid. The insulating material becomes permanently damaged by excessive temperature, the damage increasing with the length of time that the excessive temperature is maintained, and with the amount of excess temperature, until finally the insulation breaks down.

301 The result of operating at temperatures in excess of the safe limit is to shorten the life of the insulating material. This shortening of life is, in certain special cases, warranted, when necessary for obtaining some other desirable result, as, for example, in some instances of railway and other motors for propelling vehicles, in providing greater power within a limited space. See **§804**. Further instances may also be noted in the cases of contactors, controllers, induction-starters, arc-lamp-magnet windings, etc., designed and constructed for operation at relatively high temperatures.

302 There does not appear to be any advantage in operating at lower temperatures than the safe limits, so far as the life of the insulation is concerned. Insulation may break down from various causes, and when these breakdowns occur, it is not usually due to the temperature at which the insulation has been operated, provided the safe limits have not been exceeded.

303 **The Ambient Temperature** is the temperature of the air or water which, coming into contact with the heated parts of a machine, carries off its heat. See **§§309, 310** and **314.**

304 **The cooling fluid may** either be led to the machine through ducts, or through pipes, or merely surround the machine freely. In the former case the ambient temperature is to be measured at the intake of the machine itself. In the latter case see **§314.**

305 **Ambient Temperature of Reference for Air.** The standard ambient temperature of reference, when the cooling medium is air, shall be 40°C.

305A. **Whatever may be the Ambient Temperature** when the machine is in service, the limits of the maximum observable temperature and of temperature rise specified in the rules should not be exceeded in service; for, if the maximum temperature be exceeded, the insulation may be endangered, and if the rise be exceeded, the excess load may lead to injury, by exceeding limits other than those of temperature; such as commutation, stalling load and mechanical strength. For similar reasons, load in excess of the rating should not be taken from a machine.

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306 The permissible rises in temperature given in column 2 of table III in **§376** have been calculated on the basis of the standard ambient temperature of reference, by subtracting 40° from the highest temperatures permissible, which are given in column 1 of the same table.

307 A machine may be tested at any convenient ambient temperature, preferably not below 15°C., but *whatever be the value of this ambient temperature, the permissible rises of temperature must not exceed those given in column 2 of the table in* **§376.**

308 **Altitude.** Increased altitude has the effect of increasing the temperature rise of some types of machinery. In the absence of information in regard to the height above sea level at which the machine is intended to work in ordinary service, this height is assumed not to exceed 1000 meters (3300 feet.) For machinery operating at an altitude of 1000 meters or less, a test at any altitude less than 1000 meters is satisfactory, and no correction shall be applied to the observed temperatures. Machines intended for operation at higher altitudes shall be regarded as special. See **§267.** It is recommended that when a machine is intended for service at altitudes above 1000 meters (3300 ft.) the permissible temperature rise at sea level, until more nearly accurate information is available, shall be reduced by 1 per cent for each 100 meters (330 ft.) by which the altitude exceeds 1000 meters. Water cooled oil transformers are exempt from this reduction.

309 **Ambient Temperature of Reference for Water-Cooled Machinery.** For water-cooled machinery, the standard temperature of reference for incoming cooling water shall be 25° C, measured at the intake of the machine.

310 **In the testing of water-cooled transformers,** it is not necessary to take into account the surrounding air temperature, except where the cooling effect of the air is 15 per cent or more of the total cooling effect, referred to the standard ambient temperature of reference of 25°C. for water and 40°C. for air. When the effect of the cooling air is 15 per cent. or more of the total, the temperature of the cooling water should be maintained within 5°C. of the surrounding air. Where this is impractical, the ambient temperature should be determined from the change in the resistance of the windings, using a disconnected transformer, supplied with the normal amount of cooling water, until the temperature of the windings has become constant.

311 **In the case of rotating machines,** cooled by forced draught, a conventional weighted mean shall be employed, a weight of four being given to the temperature of the circulating air supplied through ducts (see §304), and a weight of one to the surrounding room air. **In the case of air-cooled transformers,** see "exception" **§321.**

312 **Machines Cooled by Other Means.** Machines cooled by means other than air or water shall receive special consideration.

313 **Outdoor Machinery Exposed to Sun's Rays.** Outdoor machinery not protected from the sun's rays at times of heavy load, shall receive special consideration.

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314 **Measurement of the Ambient Temperature During Tests of Machinery.** The ambient temperature is to be measured by means of several thermometers placed at diffe ent points around and half-way up the machine, at a distance of 1 to 2 meters (3 to 6 feet), and protected from drafts, and abnormal heat radiation, preferably as in **§316.**

315 The value to be adopted for the ambient temperature during a test, is the mean of the readings of the thermometers (placed as above), taken at equal intervals of time during the last quarter of the duration of the test.

316 In order to avoid **errors due to the time lag** between the temperature of large machines and the variations in the ambient air, all reasonable precautions must be taken to reduce these variations and the errors arising therefrom. Thus, the thermometer for determining the ambient temperature shall be immersed in a suitable liquid, such as oil, in a suitable heavy metal cup. This can be made to respond to various rates of change, by proportioning the amount of oil to the metal in the containing cup. A convenient form for such an oil-cup consists of a massive metal cylinder, with a hole drilled partly through it. This hole is filled with oil and the thermometer is placed therein with its bulb well immersed. The larger the machine under test, the larger should be the metal cylinder employed as an oil-cup in the determination of the ambient temperature. The smallest size of oil cup employed in any case shall consist of a metal cylinder 25 mm. in diameter and 50 mm. high (1 in. in diameter and 2 in. high).

317 **Thermometers used for taking temperatures of Machinery** shall be covered by felt pads 3 mm. ($\frac{1}{8}$ inch) thick and 4 x 5 cm. wide ($1\frac{1}{2}$ "x 2"), cemented on; oil putty may be used for stationary and small apparatus.

318 **In Transformer Testing,** and sometimes in testing other machines, it may be desirable to avoid errors due to time lag in temperature changes, by employing an idle unit of the same size and subjected to the same conditions of cooling as the unit under test, for obtaining the ambient temperature as described in **§310.**

319 Where **machines are partly below the floor line** in pits, the temperature of the rotor shall be referred to a weighted mean of the pit and room temperatures, the weight of each being based on the relative proportions of the rotor in and above the pit. Parts of the stator constantly in the pit shall be referred to the ambient temperature in the pit.

320 **Correction for the Deviation of the Ambient Temperature of the Cooling Medium, at the Time of the Heat Test, from the Standard Ambient Temperature of Reference.** Numerous experiments have shown that deviation of the temperature of the cooling medium from that of the standard of reference, at the time of the heat run, has a negligible effect upon the temperature rise of the apparatus; therefore, no correction shall be applied for this deviation. It is, however, desirable that tests should be conducted at ambient temperatures not lower than 15°C.

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321 *Exception*—**A Correction shall be applied** to the observed temperature rise of the windings of *Air-blast transformers*, due to difference in resistance, when the temperature of the ingoing cooling air differs from that of the standard of reference. This correction shall be the ratio of the inferred absolute ambient temperature of reference to the inferred absolute temperature of the ingoing cooling air, *i. e.* the ratio $274.5/(234.5 + t)$; where t is the ingoing cooling-air temperature.

Thus, a cooling-air room temperature of 30°C. would correspond to an inferred absolute temperature of 264.5° on the scale of copper resistivity, and the correction to 40°C. (274.5° inferred absolute temperature) would be 274.5 / 264.5 = 1.04, making the correction factor 1.04; so that an observed temperature rise of say 50°C. at the testing ambient temperature of 30°C. would be corrected to 50 × 1.04 = 52°C. this being the temperature rise which would have occurred had the test been made with the standard ingoing cooling-air temperature of 40°C.

322 **Duration of Temperature Test of Machine for Continuous Service.** The temperature test shall be continued until sufficient evidence is available to show that the maximum temperature and temperature rise would not exceed the requirements of the rules, if the test were prolonged until a steady final temperature was reached.

323 **Duration of Temperature Test of Machine with a Short-Time Rating.** The duration of the temperature test of a machine with a short-time rating shall be the time required by the rating. (See §285 and 286).

324 **Duration of Temperature Test for Machine having more than One Rating.** The duration of the temperature test for a machine with more than one rating shall be the time required by that rating which produces the greatest temperature rise. In cases where this cannot be determined beforehand, the machine shall be tested separately under each rating.

325 **Temperature Measurements during Heat Run.** Temperature measurements, when possible, shall be taken during operation, as well as when the machine is stopped. The highest figures thus obtained shall be adopted. In order to abridge the long heating period, in the case of large machines, reasonable overloads of current, during the preliminary period, are suggested for them.

TEMPERATURE MEASUREMENTS

340 **The Life of the Insulation of a Machine** depends in great measure upon the actual temperatures attained by the different parts, rather than on the rises of temperature in those parts.

341 **The Temperatures in the Different Parts of a Machine which it** would be desirable to ascertain, are the maximum temperatures reached in those parts.

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343 As it is Usually Impossible to Determine the Maximum Temperature attained in insulated windings, it is convenient to apply a correction to the observable temperature, so as to approximate the difference between the actual maximum temperature and the observable temperature by the method used. This correction, or margin of security, is provided to cover the errors due to fallibility in the location of the measuring devices, as well as inherent inaccuracies in measurement and methods.

344 In Determining the Temperature of Different Parts of a Machine three methods are provided. The appropriate method for any particular case is set forth below.

345 Method No 1. Thermometer Method.

This method consists in the determination of the temperature, by mercury or alcohol thermometers, by resistance thermometers, or by thermocouples, any of these instruments being applied to the hottest accessible part of the *completed* machine, as distinguished from the thermocouples or resistance coils embedded in the machine as described under Method No. 3.

346 When Method No. 1 is Used, the hottest-spot temperature for windings shall be estimated by adding a hottest-spot correction of 15°C to the highest temperature observed, in order to allow for the practical impossibility of locating any of the thermometers at the hottest spot.

347 *Exception.* When the thermometers are applied directly to the surfaces of bare windings, such as an edgewise strip conductor, or a cast copper winding, a hottest-spot correction of 5°C., instead of 15°C, shall be made. For commutators, collector rings, bare metallic surfaces not forming part of a winding, or for oil in which apparatus is immersed, no correction is to be applied.

348 Method No. 2. Resistance Method.

This method consists in the measurement of the temperature of windings by their increase in resistance, corrected* to the instant of shut-down when necessary. In the application of this method, *thermometer measurements shall also be made* whenever practicable without disassembling the machine† in order to increase the probability of revealing the highest observable temperature. Whichever measurement yields the higher temperature, that temperature

*Whenever a sufficient time has elapsed between the instant of shut-down and the time of the final temperature measurement to permit the temperature to fall, suitable corrections shall be applied, so as to obtain as nearly as practicable the temperature at the instant of shut-down. This can sometimes be approximately effected by plotting a curve, with temperature readings as ordinates and times as abscissas, and extrapolating back to the instant of shut-down. In other instances, acceptable correction factors can be applied. In transformers of 200 kv-a. and less the measured temperature shall be increased one degree for every minute between the instant of shut-down and the time of the final temperature measurement, provided this time does not exceed three minutes.

In cases where successive measurements show *increasing* temperatures after shut-down, the highest value shall be taken.

†As one of the few instances in which the thermometer check cannot be applied in Method No. 2, the rotor of a turbo-alternator may be cited.

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shall be taken as the "highest observable" temperature and a hottest-spot correction of 10°C added thereto.

349 **The Temperature Coefficient of Copper** shall be deduced from the formula $1/(234.5 + t)$. Thus, at an initial temperature $t = 40°C.$, the temperature co-efficient of increase in resistance per degree centigrade rise, is $1/(274.5) = 0.00364$. The following table, deduced from the formula, is given for convenience of reference.

TABLE II.

Temperature Coefficients of Copper Resistance.

Temperature of the winding, in degrees C. at which the initial resistance is measured.	Increase in resistance of copper per °C., per ohm of initial resistance.
0	0.00 427
5	0.00 418
10	0.00 409
15	0.00 401
20	0.00 393
25	0.00 385
30	0.00 378
35	0.00 371
40	0.00 364

350 **In Circuits of Low Resistance,** other than transformer windings (see §351), where joints and connections form a considerable part of the total resistance, the measurement of temperature by the resistance method shall not be used.

351 **The Temperature of the Windings of Transformers** is always to be ascertained by Method 2. In the case of air-blast transformers, it is especially important to place thermometers on the coils near the air outlet. See §348.

352 **Method No. 3. Embedded Temperature-Detector Method.** This method consists in the use of thermo-couples or resistance temperature detectors, located as nearly as possible at the estimated hottest spot. When method No. 3 is used, it shall, when required, be checked by method No. 2; the hottest spot shall then be taken to be the highest value by either method, the required correction factors (§348 and §356) being applied in each case.

353 **By Building into the Machine** suitably placed temperature detectors, a temperature not much less than that of the hottest spot will probably be disclosed. When these devices are adopted for such

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temperature determinations, a liberal number shall be employed, and all reasonable efforts, consistent with safety, shall be made to locate them at the various places where the highest temperatures are likely to occur.

354 **Temperature-Detectors** should be placed in at least two sets of locations. One of these should be between a coil-side* and the core and one between the top and bottom coil-sides where two coil-sides per slot are used. Where only one coil-side per slot is used, one set of detectors shall be placed between coil-side and core, and one set between coil-side and wedge.

355 Method No. 3 should be applied to all stators of machines with cores having a width of 50 cm. (20 in.) and over. It should also be applied to all machines of 5000 volts and over, if of over 500 kv-a., regardless of core width. This method is not required for induction-regulators, which shall be tested as transformers.

356 **Correction Factor for Method No. 3.**—In the case of two-layer windings, with detectors between coil-sides, and between coil-side and core, add 5° C to the highest reading. In single-layer windings, with detectors between coil-side and core and between coil-side and wedge, add to the highest reading 10° C. plus 1° C. per 1000 volts above 5000 volts of terminal pressure.

TEMPERATURE LIMITS

375 Table III gives the limits for the hottest-spot temperatures of insulations. The permissible limits are indicated in column 1 of the Table. The limits of temperature rise permitted under rated-load conditions are given in column 2, and are found by subtracting 40° C. from the figures in column 1. Whatever be the ambient temperature at the time of the test, the rise of temperature must never exceed the limits in column 2 of the table. The highest temperatures, and temperature rises, attained in any machine at the output for which it is rated, must not exceed the values indicated in the Table and clauses following.

376 **Permissible Temperatures and Temperature Rises For Insulating Materials.** Table III (see next page) gives the highest temperatures and temperature rises to which various classes of insulating materials may be subjected, based on a standard ambient temperature of reference of 40°C.

377 NOTE. The Institute recognizes the ability of manufacturers to employ Class B insulation successfully at maximum temperatures of 150° C. and even higher. However, as sufficient data covering experience over a period of years at such temperatures are at present unavailable, the Institute adopts 125° C as a conservative limit for this class of insulation, and any increase above this figure should be the subject of special guarantee by the manufacturer.

*A coil side is one of the two active sides of the coil.

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TABLE III.

Permissible Temperatures and Temperature Rises for Insulating Materials.

Class	Description of Material	1 Maximum Temperature to which the material may be subjected	2 Maximum Temperature Rise
A.	Cotton, silk, paper and similar materials, when so treated or impregnated as to increase the thermal limit, or when permanently immersed in oil; also enamelled wire*	105°C	65°C
B.	Mica, asbestos and other materials capable of resisting high temperatures, in which any Class A. material or binder is used for structural purposes only, and may be destroyed without impairing† the insulating or mechanical qualities of the insulation	125°C	85°C
C.	Fireproof and refractory materials, such as pure mica, porcelain, quartz, etc	No limits specified.	

*For cotton, silk, paper and similar materials, when neither treated, impregnated nor immersed in oil, the highest temperatures and temperature rises shall be 10°C below the limits fixed for Class A, in Table III.

†The word impair is here used in the sense of causing any change which would disqualify the insulation for continuous service.

378 When a lower-temperature class material is comprised in a completed product to such an extent, or in such ways, that its subjection to the temperature limits allowed for the higher-temperature class material, with which it is associated, would affect the integrity of the insulation either mechanically or electrically, the permissible temperature shall be fixed at such a value as shall afford ample assurance that no part of the lower-temperature class material shall be subjected to temperatures higher than those approved by the Institute and set forth above.

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TABLE IV

Permissible Hottest Spot Temperatures and Limiting Observable Temperature Rises in Other than Water-Cooled Machinery

			Class	A*	B
			Permissible Hottest-Spot Temperature....	105°	125°
METHOD I	Thermometer only See §345 to §347		Hottest Spot Correction.....	15°	15°
			Limiting Observable Temperature.....	90°	110°
			Limiting Observable Temperature Rise	50°	70°
METHOD II	Resistance See §348		Hottest Spot Correction.....	10°	10°
			Limiting Observable Temperature.....	95°	115°
			Limiting Observable Temperature Rise	55°	75°
METHOD III	Embedded Temperature Detectors See §§ 352 to §356	Double-Layer Windings. For all Voltages	Hottest Spot Correction.....	5°	5°
			Limiting Observable Temperature.....	100°	120°
			Limiting Observable Temperature Rise.....	60°	80°
		Single-Layer Windings. For 5000 volts or less	Hottest Spot Correction.....	10°	10°
			Limiting Observable Temperature.....	95°	115°
			Limiting Observable Temperature Rise.....	55°	75°
		Single-Layer Windings. For more than 5000 Volts	Hottest Spot Correction	10° + (*E*−5)†	10° + (*E*−5)
			Limiting Observable Temperature.....	95° − (*E*−5)	115° − (*E*−5)
			Limiting Observable Temperature Rise	55° − (*E*−5)	75° − (*E*−5)

*For cotton, silk, paper and similar materials, when neither treated, impregnated nor immersed in oil, the highest temperatures and temperature rise shall be 10°C. below the limits fixed for class A.

†In these formulas, *E* represents the rated pressure between terminals in kilovolts. Thus for a three-phase machine with single-layer winding, and with 11 kilovolts between terminals, the hottest-spot correction to be added to the maximum observable temperature will be 16°C.

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Special Cases of Temperature limits.

385 **Temperature of Oil.** The oil in which apparatus is permanently immersed shall in no part have a temperature, observable by thermometer, in excess of 90°C.

386 **Water-Cooled Transformers.** In these the hottest-spot temperature shall not exceed 90°C.

386A **Enclosed Motors and Generators.** In an enclosed machine (see **§164**) the limiting observable temperature and the limiting observable temperature rise shall be taken as 5°C. higher than in Table IV. This is not to be interpreted as an increase in the permissible hottest spot temperature, but is in recognition of the lesser difference between the hottest spot temperature and the observable temperature within an enclosed machine. This rule does not apply to those types of machines defined in §§**163, 165** and **167.**

387 **Railway Motor Temperature Limits,** see **§804** and **805.**

387A. **Automobile Propulsion Motors and Generators,** see **§838.**

388 **Squirrel-Cage and Amortisseur Windings.** In many cases the insulation of such windings is largely for the purpose of making the conductors fit tightly in their slots, and the slightest effective insulation is ample. In other cases, there is practically no insulating material on the windings. Consequently, the temperature rise may be of any value such as will not occasion mechanical injury to the machine.

389 **Collector Rings.** The temperature of collector rings shall not be permitted to exceed the " hottest-spot " values set forth in **§376** and **379** for the insulations employed either in the collector rings themselves. or in adjacent insulations whose life would be affected by the heat from the collector rings.

390 **Commutators.** The observable temperature shall in no case be permitted to exceed the values given in **§376** and **379** for the insulation employed, either in the commutator or in any insulation whose life would be affected by the heat of the commutator. These temperature limits are intended only to protect the insulation of the commutator and of the adjacent parts, and are not intended as a criterion of successful commutation. See **§402.**

391 **Cores.** The temperature of those parts of the iron core in contact with insulating materials must not be such as to occasion in those insulating materials temperatures or temperature rises in excess of those set forth in **§376** and **379.**

392 **Other parts,** (such as brush-holders, brushes, bearings, pole-tips, cores, etc.) All parts of electrical machinery other than those whose temperature affects the temperature of the insulating material, may be operated at such temperatures as shall not be injurious in any respect.

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METHODS OF LOADING TRANSFORMERS FOR TEMPERATURE TESTS

393 Whenever practicable, transformers should be tested under conditions that will give losses approximating as nearly as possible to those obtained under normal or specified load conditions, maintained for the required time (See §322 to 324). The maximum temperature rises measured during this test should be considered as the observable temperature rises for the given load.

An approved method of making these tests is the "**loading-back**" method. The principal variations of this method are:

394 **With duplicate single-phase transformers.**

Duplicate single-phase transformers may be tested in banks of two, with both primary and secondary windings connected in parallel. Normal magnetizing voltage should then be applied and the required current circulated from an auxiliary source. One transformer can be held under normal voltage and current conditions, while the other may be operating under slightly abnormal conditions.

395 **With one three-phase transformer.**

One three-phase transformer may be tested in a manner similar to §394 provided the primary and secondary windings are each connected in delta for the test. Normal three-phase magnetizing voltage should be applied and the required current circulated from an auxiliary single-phase source.

396 **With three single-phase transformers.**

Duplicate single-phase transformers may be tested in banks of three, in a manner similar to §395 by connecting both primary and secondary windings in delta, and applying normal three-phase magnetizing voltage and circulating the required current from an auxiliary single-phase source.

397 NOTE:— Among other methods that have a limited application and can be used only under special conditions may be mentioned—

(1) Applying dead load by means of some form of rheostat.

(2) Running alternately for certain short intervals of time on open circuit and then on short circuit, alternating in this way until the transformer reaches steady temperature. In this test, the voltage for the open-circuit interval and the current for the short-circuit interval shall be such as to give the same integrated core loss, and the same integrated copper loss, as in normal operation.

ADDITIONAL REQUIREMENTS

398 **Short-Circuit Stresses.**

The Institute recognizes the self-destructibility, both mechanical and thermal, of certain sizes and types of machines, when subjected to severe short-circuits, and recommends that ample protection be provided in such cases, external to the machine if necessary.

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Over-Speeds.

399 **All Types of Rotating Machines** shall be so constructed that they will safely withstand an over-speed of 25 per cent, except in the case of steam turbines, which, when equipped with emergency governors, shall be constructed to withstand 20 per cent over-speed.

400 **In the case of Series Motors,** it is impracticable to specify percentage values for the guaranteed over-speed, on account of the varying service conditions.

401 **Water-wheel Generators** shall be constructed for the maximum runaway speed which can be attained by the combined unit.

Momentary Loads.

402 **Continuously Rated Machines** shall be required to carry momentary loads of 150 per cent of the amperes corresponding to the continuous rating, keeping the rheostat set for rated load excitation, (See §281, 764 and 803.) and commutating machinery shall commutate successfully under this condition. Successful commutation is such that neither brushes nor commutator are injured by the test. In the case of direct-connected generators, this clause is not to be interpreted as requiring the prime mover to drive the generator at this overload.

403 **Machines for duty-cycle operation** shall be rated according to their equivalent load, either on the short-time or continuous basis, but if intended for operation with widely fluctuating loads, shall commutate successfully under their specified operating conditions. See §284, 285.

404 **Stalling Torque of Motors**

Motors for continuous service shall, except when otherwise specified, be required to develop a running torque at least 175 per cent of that corresponding to the running torque at their rated load, without stalling.

Obviously, duty-cycle machines must carry their peak loads without stalling.

WAVE FORM

405 The **Sine Wave** shall be considered as standard, except where deviation therefrom is inherent in the operation of the system of which the machine forms a part.

406 **The deviation of wave form** from the sinusoidal is determined by superposing upon the actual wave, (as determined by oscillograph), the equivalent sine wave of equal length, in such a manner as to give the least difference between ordinates, and then dividing the maximum difference between corresponding ordinates by the maximum value of the equivalent sine wave. A maximum deviation of the terminal voltage wave on open circuit from sinusoidal shape not exceeding 10 per cent is permissible, except when otherwise specified.

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EFFICIENCY AND LOSSES

420 **Machine Efficiency** is the ratio of the power delivered by the machine to the power received by it.

421 **Plant or System Efficiency** is the ratio of the energy delivered from the plant or system to the energy received by it in a specified period of time.* In calculating plant or system efficiency it may be desirable to calculate the losses in each individual machine or part of the system at the actual temperature of that machine or part during the specified interval. These losses may be appreciably different from the losses at 75°C., which latter shall be the standard temperature of reference for all efficiency guarantees. See §432.

422 **In the Case of Machinery two Efficiencies are Recognized,** conventional efficiency (see §423) and directly measured efficiency. Unless otherwise specified, the conventional efficiency is to be employed. When the efficiency of a machine is stated without specific reference to the load conditions, rated load is always to be understood whether the efficiency be the conventional or directly measured efficiency.

423 **Conventional Efficiency** of machinery is the ratio of the output to the sum of the output and the losses; or of the input minus the losses to the input; when, in either case, conventional values are assigned to one or more of these losses. The need for assigning conventional values to certain losses, arises from the fact that some of the losses in electrical machinery are practicably indeterminable, and must, in many cases, either be approximated by an approved method of test, or else values recommended by the Institute and designated "conventional" values shall be employed for them in arriving at the "conventional efficiency."

425 **Directly-Measured Efficiency.** Input and output determinations of efficiency may be made directly, measuring the output by brake, or equivalent, where applicable. Within the limits of practical application, the circulating-power method, sometimes described as the Hopkinson or "loading-back" method, may be used.

426 **Values of the Indeterminate Losses** may also be obtained by brake or other direct test, and used in estimating actual efficiencies of similar machines, by the separate-loss method.

427 **Normal Conditions.** The efficiency shall correspond to, or be corrected to, the normal conditions herein set forth, which shall be regarded as standard. These conditions include voltage, current, power-factor, frequency, wave-shape, speed, temperature, or such of them as may apply in each particular case.

428 **Measurement of Efficiency.** Electric power shall be measured at the terminals of the apparatus. In polyphase machines, sufficient measurements shall be made on all phases to avoid errors of unbalance.

429 **Point at Which Mechanical Power Shall be Measured.** Mechanical power delivered by machines, shall be measured at the pulley,

*An exception should be noted in the case of the efficiency of storage batteries.

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gearing, or coupling, on the rotor shaft, thus excluding the loss of power in the belt or gear friction. See, however, an exception in §800.

430 **The Efficiency Specified for Alternators and Transformers** shall be of the ratio of the kilowatt output to the kilowatt input at the rated kv-a. and power factor.

431 **Efficiency of Alternating-Current Machinery in regard to Wave Shape.** In determining the efficiency of alternating-current machinery, the sine wave is to be considered as standard, unless a different wave form is inherent in the operation of the system. See §405.

432 **Temperature of Reference for Machine Efficiency.** The efficiency, at all loads, of all apparatus, shall be corrected to a reference temperature of 75°C, but tests may be made at any convenient ambient temperature, preferably not less than 15°C. See §§348 and 445.

433 **The losses in constant-potential machinery,** either of the stationary type, or of the constant-speed rotary type, are of two classes; namely, those which remain substantially constant at all loads, and those which vary with the load. The former include iron losses, windage and friction, also I^2R losses in any shunt windings. The latter include I^2R losses in series windings. The constant losses may be determined by measuring the power required to operate the machine at no load, deducting any series I^2R losses. The variable loss at any load may be computed from the measured resistance of the series windings and the given load current.

434 **Stray Load Losses.** The above simple method of determining the losses and hence the efficiency is only approximate, since the losses which are assumed to be constant do actually vary to some extent with the load, and also because the actual loss in the copper windings is sometimes appreciably greater than the calculated I^2R loss. The difference between the approximate losses, as above determined, and the actual losses, is termed the "stray load losses"*. These latter are due to distortions in electric or magnetic fluxes from their no-load distributions or values, brought about by the load current. They are usually only approximately measurable, or may be indeterminable.

*In Table V, the stray load losses include f, h, i, k, l and m; but do not include increased core losses due to increased excitation for compensating internal drop under load.

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TABLE V

Classification of Losses in Machinery

435 Losses in machinery may be classified as follows:

Accurately Measurable or Determinable	*Approximately Measurable or Determinable*	*Indeterminable*
a. No-Load Core Losses including eddy-current losses in conductors at no-load	*c*. Brush Friction Loss	*h*. Iron Loss due to flux distortion.
b. Load I^2R losses in windings No-Load I^2R " " "	*d*. Brush-Contact Loss	*i*. Eddy-Current losses in conductors due to transverse fluxes occasioned by the load currents.
	e. Losses due to windage and to bearing friction	*k*. Eddy-Current losses in conductors due to tooth saturation resulting from distortion of the main flux.
	f. Extra copper loss in transformer windings, due to stray fluxes caused by load currents	*l* Tooth-frequency losses due to flux distortion under load.
	g. Dielectric Losses.	*m*. Short-Circuit Loss of Commutation.

436 Evaluation of Losses. The larger individual losses are either accurately or approximately determinable, but certain of the indeterminable losses reach values in various kinds of machinery which require that they should be taken into account.

LOSSES TO BE TAKEN INTO ACCOUNT IN VARIOUS TYPES OF MACHINES

440 Direct-Current Commutating Motors and Generators.

Core losses. See §452.

I^2R loss in all windings.

Brush contact I^2R loss. Unless otherwise specified, use the Institute Standard of 1 volt for contact drop per brush; *i. e.*, 2 volts for total brush drop, either carbon or graphite brushes. (See §§454 and 819). In the case of low voltage automobile propulsion motors and generators this loss should be determined experimentally; see §839.

Friction of bearings and windage.

Rheostat losses, when present.

Brush friction.

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All indeterminable load losses (including stray-load iron losses) which may be important, which vary with the design, and for which no satisfactory method of determination has been found, shall be included as zero per cent in estimating conventional efficiency.

441 Synchronous Motors and Generators.

Core losses. See **§452.**

I^2R loss in all windings, based upon rated k-va. and power factor.

Stray load-losses. In approximating these losses, the method described in **§458** shall be employed.

Friction of bearings and windage.

Brush friction and brush-contact loss is negligible, except in the case of revolving armature machines.

Rheostat losses, when present, corresponding to rated kv-a. and power factor.

442 Induction Machines.

Core losses. See **§452.**

I^2R losses in all windings.

Stray load-losses. In approximating these losses, the method described in **§459** shall be employed

Brush friction when collector rings are present.

Brush-contact loss. Unless otherwise specified, use the Institute Standard of 1 volt for contact drop per brush, for either carbon or graphite brushes. See **§454.**

Friction of bearings and windage.

443 Commutating A-C. Machines

Core losses. See **§452.**

I^2R losses in all windings.

Brush friction.

Brush-contact loss. Unless otherwise specified, use the Institute Standard of 1 volt for contact drop per brush, for either carbon or graphite brushes. See **§454** and **819.**

Friction of bearings and windage.

Short-circuit loss of commutation.
Iron loss due to flux distortion.
Eddy-current losses due to fluxes varying with load and saturation.

} The Institute is not at this time prepared to make recommendations for approximating these losses.

444 Synchronous Converters.

Core losses. See **§452.**

I^2R losses in all windings, based on rated kw. and unity power factor. The I^2R losses in the armature winding shall be derived from those corresponding to its use as a direct-current generator, by using suitable factors.

Brush friction.

Rheostat losses when present, corresponding to rated kw. and unity power factor.

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Brush-contact loss. Unless otherwise specified, use the Institute Standard of 1 volt for contact drop per brush, for either carbon or graphite brushes. See **§454.**

Short-circuit loss of commutation.
Iron loss due to flux distortion when present.
Eddy-current losses due to fluxes varying with load and saturation.

} These losses, while usually of low magnitude, are erratic, and the Institute is not at this time prepared to make recommendations for approximating them.

Friction of bearings and windage.

For the booster type of synchronous converter, where the booster forms an integral part of the unit, its losses shall be included in the total converter losses in estimating the efficiency.

445 Transformers

No-load losses. These include the core loss, and the I^2R loss due to the exciting current, also the dielectric loss in the insulation. (See **§470**).

Load losses. These include I^2R losses, and stray load-losses due to eddy currents caused by fluxes varying with load. (See **§471**).

DETERMINATION OR APPROXIMATION OF LOSSES IN ROTATING MACHINERY

450 Bearing Friction and Windage may be determined as follows. Drive the machine from an independent motor, the output of which shall be suitably determined. The machine under test shall have its brushes removed and shall not be excited. This output represents the bearing friction and windage of the machine under test.

The bearing friction and windage of induction motors may be measured by running motors free at the lowest voltage at which they will rotate continuously at approximately rated speed; the watts input, minus I^2R loss, under these conditions being taken as the friction and windage.

In the case of engine-type generators, the windage and bearing friction loss is ordinarily very small, amounting to a fraction of one per cent of the output. In these rules this loss is neglected owing to its small value and the difficulty of measuring it.

451 Brush Friction of Commutator and Collector Rings. Follow the test of **§450,** taking an additional reading with the brushes in contact with the commutator or collector rings. The difference between the output obtained in the test in **§450** and this output shall be taken as the brush friction. Note: The surfaces of the commutator and brushes should already be smooth and glazed from running when this test is made.

452 Core Loss. Follow the test of **§451** with an additional reading taken in a similar manner, except that the machine is to be excited

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so as to produce at the terminals a voltage corresponding to the calculated internal voltage for the load under consideration. The difference between the output obtained by this test and that obtained by test under Sec. **451** shall be taken as the core loss.

For Synchronous Machines, the internal voltage shall be determined by correcting the terminal voltage for the resistance drop only.

The Core Loss of Induction Motors may be determined by measuring the watts input to the motor when running free at rated voltage and frequency and subtracting therefrom the no-load copper loss, bearing friction and windage.

454 **The Brush-Contact I^2R Loss** depends largely upon the material of which the brush is composed. As indicating the range of variation the following table will be of interest:

TABLE VI.

Brush-Contact Drop.

Grade of Brush	Volts drop across one brush-contact. (Average of positive and negative brushes)
Hard Carbon	1.1
Soft Carbon	0.9
Graphite	0.5 to 0.8
Metal-Graphite types	0.15 to 0.5 (The former for largest proportion of metal)

One volt drop per brush shall be considered as the Institute Standard drop corresponding to the I^2R brush-contact loss, for carbon and graphite brushes. Metal-graphite brushes shall be considered as special. See **§819**.

455 **Field-Rheostat Losses** shall be included in the generator losses where there is a field rheostat in series with the field magnets of the generator, even when the machine is separately excited.

456 **Ventilating Blower.** When a blower is supplied as part of a machine set, the power required to drive it shall be charged against the complete unit; but not against the machine alone.

457 **Losses in Other Auxiliary Apparatus.** Auxiliary apparatus, such as a separate exciter for a generator or motor, shall have its losses charged against the plant of which the generator and exciter are a part, and not against the generator. An exception should be noted in the case of turbo-generator sets with direct-connected exciters, in which case the losses in the exciter shall be charged against the generator. The actual energy of excitation and the

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field-rheostat losses, if any, (see §455) shall be charged against the generator.

458 **Stray Load-Losses in Synchronous Generators and Motors.** These include iron losses, and eddy-current losses in the copper, due to fluxes varying with load and also to saturation.

Stray load-losses are to be determined by operating the machine on short circuit and at rated-load current. This, after deducting the windage and friction and I^2R loss, gives the stray load-loss for polyphase generators and motors. These losses in single-phase machines are large; but the Institute is not yet prepared to specify a method for measuring them.

459 **Stray Load-Losses in Induction Machines.**

These include eddy-current losses in the stator copper, and other eddy-current losses due to fluxes varying with the load. In windings consisting of relatively small conductors, these eddy-current losses are usually negligible.

With rotor removed, measure the power input to the stator with different values of current at the rated frequency. The curve plotted with these values gives the combined I^2R and stray load-losses due to eddy currents in the stator copper. Deduct the I^2R loss determined from the resistance, and the difference will represent the stray load-losses corresponding to the various currents. While this method is not accurate for some types of motors it usually represents a sufficiently good approximation.

460 **Polyphase Induction-Motor Rotor I^2R Loss.** This should be determined from the slip, whenever the latter is accurately determinable, using the following equation:

$$\text{Rotor } I^2R \text{ loss} = \frac{\text{Output} \times \text{slip}}{1 - \text{slip}}$$

In large slip-ring motors, in which the slip cannot be directly measured by loading, the rotor I^2R loss shall be determined by direct resistance measurement; the rotor full-load current to be calculated by the following equation:

$$\text{Current per ring} = \frac{\text{watts output}}{\text{rotor voltage at stand-still} \times \sqrt{3} \times K}$$

This equation applies to three-phase rotors. For rotors wound for two phase, use 2 instead of the $\sqrt{3}$. K may be taken as 0.95 for motors of 150 kw. or larger. The factor K usually decreases as the size of motor is reduced, but no specific value can be stated for smaller sizes.

DETERMINATION OR APPROXIMATION OF LOSSES IN TRANSFORMERS

470 **No-Load Losses.** These shall be measured with open secondary circuit at the rated frequency, and with an applied primary voltage

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giving the rated secondary voltage plus the IR drop which occurs in the secondary under rated load conditions.

471 Load Losses. These include I^2R and stray load-losses. They shall be measured by applying a primary voltage, preferably at rated frequency, sufficient to produce rated load current in the windings, with the secondary windings short circuited.

TESTS OF DIELECTRIC STRENGTH OF MACHINERY

480 Basis for Determining Test Voltages. The test voltage which shall be applied to determine the suitability of insulation for commercial operation is dependent upon the kind and size of the machinery, and its normal operating voltage, upon the nature of the service in which it is to be used, and upon the severity of the mechanical and electrical stresses to which it may be subjected. The voltages and other conditions of test which are recommended, have been determined as reasonable and proper for the great majority of cases, and are proposed for general adoption, except when specific reasons make a modification desirable.

481 Condition of Machinery to be Tested. Commercial tests shall, in general, be made with the completely assembled machinery and not with individual parts. The machinery shall be in good condition, and high-voltage tests, unless otherwise specified, shall be applied before the machine is put into commercial service, and shall not be applied when the insulation resistance is low owing to dirt or moisture. High-voltage tests shall be made at the temperature assumed under normal operation or at the temperature attained under the conditions of commercial testing. High-voltage tests to determine whether specifications are fulfilled, are admissible on new machines only. Unless otherwise agreed upon, high-voltage tests of a machine shall be understood as being made at the factory.

482 Points of Application of Voltage. The test voltage shall be successively applied between each electric circuit and all other electric circuits and metal parts grounded.

483 Interconnected Polyphase Windings are considered as one circuit. All windings of a machine except that under test, shall be connected to ground.

484 Frequency, Wave Form and Test Voltage. The frequency of the testing circuit shall not be less than the rated frequency of the apparatus tested. A sine-wave form is recommended. See §405. The test shall be made with alternating voltage having a crest value equal to $\sqrt{2}$ times the specified test voltage. In d.c. machines, and in the general commercial application of a.c. machines, the testing frequency of 60 cycles per second is recommended.

485 Duration of Application of Test Voltage. The testing voltage for all classes of apparatus shall be applied continuously for a period of 60 seconds

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485A **For All Standard Devices Produced in Large Quantities** and with a standard test pressure of 2500 volts or less, a test pressure applied for one second 20 per cent higher than the one-minute test pressure will be satisfactory.

486 **Apparatus for Use on Single-Phase, 3-Phase-Delta or 3-Phase-Star Circuits.** Apparatus, such as transformers, which may be used in star connection on three-phase circuits, shall have the delta voltage of the circuits on which they may be used indicated on the rating plate and the test shall be based on such delta voltage.

VALUES OF A-C. TEST VOLTAGES

500 **The Standard Test for All Classes of Apparatus, Except as Otherwise Specified, Shall be Twice the Normal Voltage of the Circuit to Which the Apparatus is Connected, Plus 1000 Volts.**

501 *Exception*—**Alternating-Current Apparatus connected to Permanently Grounded Single-Phase Systems, for use on Permanently Grounded Circuits of more than 300 Volts,** shall be tested with 2.73 times the voltage of the circuit to ground + 1000 volts. **This does not refer to three-phase apparatus with grounded star neutral.**

502 *Exception*—**Distributing Transformers.** Transformers for primary pressures from 550 to 5000 volts, the secondaries of which are directly connected to consumers' circuits and commonly known as distributing transformers, shall be tested with 10,000 volts from primary to core and secondary combined. The secondary windings shall be tested with twice their normal voltage plus 1000 volts.

503 *Exception*—**Auto-Transformers** used for starting purposes, shall be tested with the same voltage as the test voltage of the apparatus to which they are connected.

504 *Exception*—**Household Devices.** Apparatus taking not over 660 watts† and intended solely for operation on supply circuits not exceeding 250 volts, shall be tested with 900 volts, except in the case of heating devices which shall be tested with 500 volts at operating temperature.

505 *Exception*—**Apparatus for use on Circuits of 25 Volts or Lower,** such as bell-ringing apparatus,* electrical apparatus used in automobiles, apparatus used on low-voltage battery circuits, etc., shall be tested with 500 volts.

506 *Exception*—**Field Windings of Alternating-Current Generators** shall be tested with 10 times the exciter voltage, but in no case with less than 1500 volts nor more than 3500 volts.

507 *Exception*—Field Windings‡ of Synchronous Machines, including motors and converters which are to be started from alternating-current circuits, shall be tested as follows:

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†The present National Electric Code power limit for a single outlet.

*This rule does not include bell-ringing transformers of ratio 125 to 6 volts. See National Electric Code.

‡Series field coils should be regarded as part of the armature circuit and tested as such.

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a. When machines are started with fields short-circuited they shall be tested as specified in §506.

b. When machines are started with fields open-circuited and sectionalized while starting, they shall be tested with 5000 volts.

c. When machines are started with fields open-circuited and connected all series while starting, they shall be tested with 5000 volts for less than 275-volt excitation and 8000 volts for excitation of 275 volts to 750 volts.

508 *Exception.* **Phase-Wound Rotors of Induction Motors.** The secondary windings of wound rotors of induction motors shall be tested with twice their normal induced voltage, plus 1000 volts. By normal induced voltage is here meant the voltage between slip rings on open circuit at standstill with normal voltage impressed on the primary.

When induction motors with phase-wound rotors are reversed, while running at approximately normal speed, by reversing the primary connections, the test shall be four times the normal induced voltage, plus 1000 volts.

509 *Exception*—**Switches and Circuit Control Apparatus** above 600 volts, shall be tested with 2½ times rated voltage, plus 2000 volts. See §720 to 741.

510 *Exception*—**Assembled Apparatus.** Where a number of pieces of apparatus are assembled together and tested as an electrical unit, they shall be tested with 15 per cent lower voltage than the lowest required on any of the individual pieces of apparatus.

510A *Exception.* **Meters and Instruments.** The Institute is not at present in a position to make a recommendation in regard to the dielectric tests of meters and instruments.

511 **Testing Transformers by Induced Voltage.** Under certain conditions it is permissible to test transformers by inducing the required voltage in their windings, in place of using a separate testing transformer. By "required voltage", is meant a voltage such that the line end of the windings shall receive a test to ground equal to that required by the general rules.

512 **Transformers with Graded Insulation** shall be so marked. They shall be tested by inducing the required test-voltage in the transformer and connecting the successive line leads to ground.

Transformer windings permanently grounded within the transformer shall be tested by inducing the required test voltage in such windings. (See §500).

MEASUREMENT OF VOLTAGE IN DIELECTRIC TESTS OF MACHINERY

530 **Use of Voltmeters and Spark-Gaps in Insulation Tests.** When making insulation tests on electrical machinery, every

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precaution must be taken against the occurrence of any spark-gap discharges in the circuits from which the machinery is being tested. A non-inductive resistance of about one ohm per volt shall be inserted in series with one terminal of the spark gap. If the test is made with one electrode grounded, this resistance shall be inserted directly in series with the non-grounded electrode. If neither terminal is grounded, one-half shall be inserted directly in series with each electrode. In any case this resistance shall be as near the measuring gap as possible and not in series with the tested apparatus. The resistance will damp high-frequency oscillations at the time of breakdown and limit the current which will flow. A water tube is the most reliable form of resistor. Carbon resistors should not be used because their resistance may become very low at high voltages.

531 **For Machinery of Low Capacitance.** When the machinery under test does not require sufficient charging current to distort the high-voltage wave shape, or change the ratio of transformation, the spark gap should be set for the required test voltage and the testing apparatus adjusted to give a voltage at which this spark gap just breaks down. This adjustment should be made with the apparatus under test disconnected. The apparatus should then be connected, and with the spark gap about 20 per cent longer, the testing apparatus is again adjusted to give the voltage of the former breakdown, which is the assumed voltage of test. This voltage is to be maintained for the required interval.

532 **For Machinery of High Capacitance.** When the charging current of the machinery under test may appreciably distort the voltage wave or change the effective ratio of the testing transformer, the first adjustment of voltage with the gap set for the test voltage should be made with the apparatus under test connected to the circuit and in parallel with the spark gap.

When making arc-over tests of large insulators, leads, etc. partial arc-over of the tested apparatus may produce oscillations which will cause the measuring gap to discharge prematurely. The measured voltage will then appear too high. In such tests the "equivalent" ratio" of the testing transformer should be measured by gap to within 20% of the arc-over voltage of the tested apparatus with the tested apparatus in circuit. The measuring gap should then be greatly lengthened out and the voltage increased until the tested apparatus arcs over. This arc-over voltage should then be determined by multiplying the voltmeter reading by the equivalent ratio found above. Direct measurement of the spark-over voltage over one gap by another gap should always be avoided.

533 **Measurements with Voltmeter.** In measuring the voltage with a voltmeter, the instrument should preferably derive its voltage from the high-tension circuit, either directly, or by means of a voltmeter coil placed in the testing transformer, or through an auxiliary *ratio transformer*. It is permissible to measure the voltage at other places, such as the transformer primary provided cor-

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rections can be made for the variations in ratio caused by the charging current of the machinery under test, or provided there is no material variation of this ratio. In any case, when the capacitance of the apparatus to be tested is such as to cause wave distortion, the testing voltage must be checked by a spark gap as set forth in §538, or by a crest voltage meter. If the crest-voltage meter is calibrated in crest volts, its readings must be reduced to the corresponding r. m. s. sinusoidal value by dividing with $\sqrt{2}$.

534 **Measurements with Spark Gaps.** If proper precautions are observed, spark gaps may be used to advantage in checking the calibration of voltmeters when set up for the purposes of high-voltage tests of the insulation of machinery.

535 **Ranges of Voltages.** For the calibrating purposes set forth in §534 the sphere-gap shall be used for voltages above 50 kv., and is to be preferred down to 30 kv. The needle spark-gap may, however, be used for voltages from 10 to 50 kv.

536 **The Needle Spark Gap.** The needle spark gap shall consist of new sewing needles, supported axially at the ends of linear conductors which are at least twice the length of the gap. There must be a clear space around the gap for a radius of at least twice the gap length.

537 The sparking distances in air between No. 00 sewing needle points for various root-mean-square sinusoidal voltages are as follows:

TABLE VII.

Needle-Gap Spark-Over Voltages

(At 25°C and 760 mm. barometer).

R M S. Kilovolts	Millimeters	R.M.S. Kilovolts	Millimeters
10	11.9	35	51
15	18.4	40	62
20	25.4	45	75
25	33	50	90
30	41		

The above values refer to a relative humidity of 80 per cent. Variations from this humidity may involve appreciable variations in the sparking distance.

538 **The Sphere Spark-Gap.** The standard sphere spark-gap shall consist of two suitably mounted metal spheres. When used as specified below, the accuracy obtainable should be approximately 2 per cent.

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No extraneous body, or external part of the circuit, shall be nearer the gap than twice the diameter of the spheres. By the "gap" is meant the shortest path between the two spheres.

The shanks should not be greater in diameter than 1/5th the sphere diameter. Metal collars, etc., through which the shanks extend, should be as small as practicable and should not, during any measurement, come closer to the sphere than the maximum gap length used in that measurement.

The sphere diameter should not vary more than 0.1 per cent and the curvature, measured by a spherometer, should not vary more than 1 per cent from that of a true sphere of the required diameter.

539 **In using the spherometer** to measure the curvature, the distance between the points of contact of the spherometer feet should be within the following limits:

TABLE VIII

Spherometer Specifications

Diameter of Sphere in m.m.	Distance between contact points in mm.	
	Maximum	Minimum
62.5	35	25
125	45	35
250	65	45
500	100	65

539A **In using Sphere Gaps** constructed as above, it is assumed that the apparatus will be set up for use in a space comparatively free from external dielectric fields. Care should be taken that conducting bodies forming part of the circuit, or at circuit potential, are not so located with reference to the gap that their dielectric fields are superposed on the gap; *e.g.*, the protecting resistance should not be arranged so as to present large masses or surfaces near the gap, even at a distance of two sphere diameters.

In case the sphere is grounded, the spark point of the grounded sphere should be approximately five diameters above the floor or ground.

540 **The sparking distances between different spheres** for various r.m.s. sinusoidal voltages shall be assumed to be as follows:

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TABLE IX.

Sphere-Gap Spark-Over Voltages

(At 25°C and 760 mm. barometric pressure)

Kilovolts	Sparking Distance in Millimeters.							
	62.5 mm. spheres		125 mm. spheres		250 mm. spheres		500 mm. spheres	
	One sphere grounded	Both spheres insulated	One sphere grounded	Both spheres insulated	One sphere grounded	Both spheres insulated	One sphere grounded	Both spheres insulated
10	4.2	4.2	..	..	..	..	..	..
20	8.6	8.6	..	..	..	..	..	..
30	14.1	14.1	14.1	14.1	..	..	..	..
40	19.2	19.2	19.1	19.1	..	..	..	..
50	25.5	25.0	24.4	24.4	..	..	..	..
60	34.5	32.0	30.	30.	29	29	..	..
70	46.0	39.5	36	36	35	35	..	..
80	62.0	49.0	42	42	41	41	41	41
90		60.5	49	49	46	45	46	45
100			56	55	52	51	52	51
120			79.7	71	64	63	63	62
140			108	88	78	77	74	73
160			150	110	92	90	85	83
180				138	109	106	97	95
200					128	123	108	106
220					150	141	120	117
240					177	160	133	130
260					210	180	148	144
280					250	203	163	158
300						231	177	171
320						265	194	187
340							214	204
360							234	221
380							255	239
400							276	257

The sphere gap is more sensitive than the needle gap to momentary rises of voltage and the voltage required to spark over the gap should be obtained by slowly closing the gap under constant voltage, or by slowly raising the voltage with a fixed setting of the gap. Open arcs should not be permitted in proximity to the gap during its operation, as they may affect its calibration.

AIR-DENSITY CORRECTION-FACTORS FOR SPHERE GAPS

541 **The Spark-Over Voltage,** for a given gap, decreases with decreasing barometric pressure and increasing temperature. This correction may be considerable at high altitudes.

The spacing at which it is necessary to set a gap to spark over at some required voltage, is found as follows: Divide the required voltage by the correction factor given below in Table X. A new

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voltage is thus obtained. The spacing on the standard curves obtained from Table IX, corresponding to this new voltage, is the required spacing.

The voltage at which a given gap sparks over is found by taking the voltage corresponding to the spacing from the standard curves of Table IX, and multiplying by the correction factor.

When the variation from sea level is not great, the relative air density may be used as the correction factor; when the variation is great, or greater accuracy is desired, the correction factor corresponding to the relative air density should be taken from Table X below, in which

$$\text{Relative air density} = \frac{0.392\,b}{273 + t}$$

b = barometric pressure in mm.

t = temperature in deg. C.

Corrected curves may be plotted for any given altitude, if desired.

Values of relative air density and corresponding values of the correction factor are tabulated below. It will be seen that for values above .9, the correction factor does not differ greatly from the relative air density.

TABLE X.

Air-Density Correction Factors for Sphere Gaps

Relative air density	Diameter of standard spheres in mm.			
	62.5	125	250	500
0.50	0.547	0.535	0.527	0.519
0.55	0.594	0.583	0.575	0.567
0.60	0.640	0.630	0.623	0.615
0.65	0.686	0.677	0.670	0.663
0.70	0.732	0.724	0.718	0.711
0.75	0.777	0.771	0.766	0.759
0.80	0.821	0.816	0.812	0.807
0.85	0.866	0.862	0.859	0.855
0.90	0.910	0.908	0.906	0.904
0.95	0.956	0.955	0.954	0.952
1.00	1.000	1.000	1.000	1.000
1.05	1.044	1.045	1.046	1.048
1.10	1.090	1.092	1.094	1.096

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INSULATION RESISTANCE OF MACHINERY

550 **The insulation resistance of a machine** at its operating temperature shall be not less than that given by the following formula:

$$\text{Insulation Resistance in megohms} = \frac{\text{voltage at terminals}}{\text{rated capacity in kv-a.} + 1000}$$

The formula only applies to dry apparatus. Such high values are not attainable in oil-immersed apparatus.

Insulation resistance tests shall, if possible, be made at a d.c. pressure of 500 volts. Since the insulation resistance varies with the pressure, it is necessary that, if a pressure other than 500 volts is to be employed in any case, this other pressure shall be clearly specified.

The order of magnitude of the values obtained by this rule is shown in the following table:

TABLE XI.

Insulation Resistance of Machinery

Rated Voltage of machine	Megohms		
	100 kv-a.	1000 kv-a.	10,000 kv-a.
100	0.091	0.05	—
1,000	0.91	0.50	0.091
10,000	9.1	5.0	0.91
100,000	—	50	9.1

551 It should be noted that the insulation resistance of machinery is of doubtful significance by comparison with the dielectric strength. The insulation resistance is subject to wide variation with temperature humidity and cleanliness of the parts. When the insulation resistance falls below that corresponding to the above rule, it can, in most cases of good design and where no defect exists, be brought up to the required standard by cleaning and drying out the machine. The insulation-resistance test may therefore afford a useful indication as to whether the machine is in suitable condition for the application of the dielectric test.

REGULATION

DEFINITIONS

560 **Regulation.** The regulation of a machine in regard to some characteristic quantity (such as terminal voltage or speed) is the change in that quantity occurring between any two loads. Unless otherwise specified, the two loads considered shall be zero load and rated load, and at the temperature attained under normal operation. The regulation may be expressed by stating the numerical values of the quantity at the two loads, or it may be ex-

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pressed by the "percentage regulation", which is the percentage ratio of the change in the quantity occurring between the two loads, to the value of the quantity at either one or the other load, taken as the normal value. It is assumed that all parts of the machine affecting the regulation maintain constant temperature between the two loads, and where the influence of temperature is of consequence, a reference temperature of 75°C shall be considered as standard. If change of temperature should occur during the tests, the results shall be corrected to the reference temperature of 75°C.

The normal value may be either the no-load value, as the no-load speed of induction motors; or it may be the rated-load value, as in the voltage of a.c. generators.

It is usual to state the regulation of d-c. generators by giving the numerical values of the voltage at no load and rated load, and in some cases it is advisable to state regulation at intermediate loads.

561 The **Regulation of d-c. Generators** refers to changes in voltage corresponding to gradual changes in load and does not relate to the comparatively large momentary fluctuations in voltage that frequently accompany instantaneous changes in load.

In determining the regulation of a compound-wound d-c. generator, two tests shall be made, one bringing the load down and the other bringing the load up, between no-load and rated load. These may differ somewhat, owing to residual magnetism. The mean of the two results shall be used.

562 In **constant-potential a-c. generators,** the regulation is the rise in voltage (when the specified load at specified power factor is reduced to zero) expressed in per cent of normal rated-load voltage.

563 In **constant-current machines,** the regulation is the ratio of the maximum difference of current from the rated-load value (occurring in the range from rated-load to short-circuit, or minimum limit of operation), to the rated-load current.

564 In **constant-speed direct-current motors,** and induction motors, the regulation is the ratio of the difference between full-load and no-load speeds to the no-load speed.

565 In **constant-potential transformers,** the regulation is the difference between the no-load and rated-load values of the secondary terminal voltage at the specified power factor (with constant primary impressed terminal voltage) expressed in per cent of the rated-load secondary voltage, the primary voltage being adjusted to such a value that the apparatus delivers rated output at rated secondary voltage.

566 In **converters, dynamotors, motor-generators and frequency converters,** the regulation is the change in the terminal voltage of the output side between the two specified loads. This may be expressed by giving the numerical values, or as the percentage of the terminal voltage at rated load.

567 In **transmission lines, feeders etc.,** the regulation is the change in the voltage at the receiving end between rated non-inductive load and no load, with constant impressed voltage upon the sending

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end. The percentage regulation is the percentage change in voltage to the normal rated voltage at the receiving end.

568 In **steam engines, steam turbines and internal combustion engines,** the percentage speed regulation is usually expressed as the percentage ratio of the maximum variation of speed, to the rated-load speed in passing slowly from rated load to no load (with constant conditions at the supply.)

569 If the test is made by passing suddenly from rated load to no load, the immediate percentage speed regulation so derived shall be termed the **fluctuation.**

570 In **a hydraulic turbine,** or other water motor, the percentage speed regulation is expressed as the percentage ratio of the maximum variation in speed in passing slowly from rated load to no load (at constant head of water), to the rated-load speed.

571 In **a generator unit,** consisting of a generator combined with a prime mover, the speed or voltage regulation should be determined at constant conditions of the prime mover; *i.e.* constant steam-pressure, head, etc. It includes the inherent speed variations of the prime mover. For this reason, the regulation of a generator unit is to be distinguished from the regulation of either the prime mover, or of the generator combined with it, when taken separately.

CONDITIONS FOR TESTS OF REGULATION

580 **Speed and Frequency.** The regulation of generators is to be determined at constant speed, and of alternating-current apparatus at constant frequency.

581 **Power Factor.** In apparatus generating, transforming or transmitting alternating currents, the power factor of the load to which the regulation refers should be specified. Unless otherwise specified, it shall be understood as referring to non-inductive load, that is to a load in which the current is in phase with the *e.m f.* at the output side of the apparatus.

582 **Wave Form.** In the regulation of alternating-current machinery receiving electric power, a sine wave of voltage is assumed, except where expressly specified otherwise. See **§405.**

583 **Excitation.** In commutating machines, rectifying machines, and synchronous machines, such as direct-current generators and motors, as well as in alternating-current generators, the regulation is to be determined under such conditions as to maintain the field adjustment constant at that which gives rated-load voltage at rated-load current, as follows:

(1) In the case of separately-excited field magnets—constant excitation.

(2) In the case of shunt machines, constant resistance in the shunt-field circuit.

(3) In the case of series or compound machines, constant resistance shunting the series-field windings.

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584 Tests and Computation of Regulation of A-C. Generators.

Any one of the three following methods may be used. They are given in the order of preference.

Method a.

The regulation can be measured directly, by loading the generator at the specified load and power factor, then reducing the load to zero, and measuring the terminal voltage, with speed and excitation adjusted to the same values as before the change. This method is not generally applicable for shop tests, particularly on large generators, and it becomes necessary to determine the regulation from such other tests as can be readily made.

585 Method b.

This consists in computing the regulation from experimental data of the open-circuit saturation curve and the zero-power-factor saturation curve. The latter curve, or one approximating very closely to it, can be obtained by running the generator with over excitation on a load of idle-running under-excited synchronous motors. The power factor under these conditions is very low and the load saturation curve approximates very closely the zero power factor saturation curve. From this curve and the open circuit curve, points for the load saturation curve, for any power factor, can be obtained by means of vector diagrams.

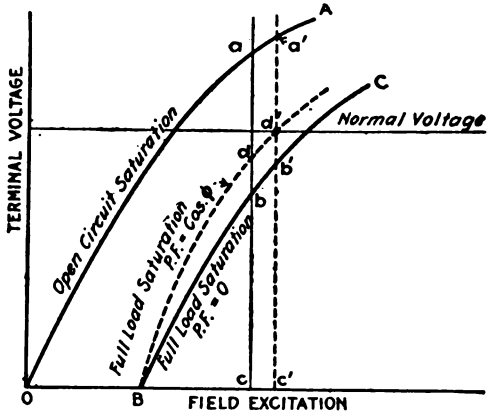

FIG. 1

To apply Method b, it is necessary to obtain from test, the open-circuit saturation curve *OA*, Fig. 1, and the saturation curve *BC* at zero power factor and rated-load current. At any given excitation *Oc*, the voltage that would be induced on open circuit is *ac*, the terminal voltage at zero power factor is *bc*, and the apparent internal drop is *ab*. The terminal voltage *dc* at any other power factor can then be found by drawing an e.m.f. diagram* as in Fig. 2, where ϕ is

*Method b, for deducing the load saturation curve, at any assigned power factor, from no-load and zero power-factor saturation curves obtained by test, must be regarded as empirical. Its value depends upon the fact that experience has demonstrated the reasonable correctness of the results obtained by it.

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an angle such that $\cos \phi$ is the power factor of the load, be the resistance drop (IR) in the stator winding, ba the total internal drop, and ac the total induced voltage; ba and ac being laid off to correspond with the values obtained from Fig. 1. The terminal voltage at power factor $\cos \phi$, is then cb of Fig. 2, which, laid off in Fig. 1, gives point d. By finding a number of such points, the curve Bdd' for power factor $\cos \phi$ is obtained and the regulation at this power factor (expressed in per cent) is $\frac{100 \times a'd'}{d'c'}$, since $a'd'$ is the rise in voltage when the load at power factor $\cos \phi$ is thrown off at normal voltage $c'd'$.

Generally, the ohmic drop can be neglected, as it has very little influence on the regulation, except in very low-speed machines where the armature resistance is relatively high, or in some cases where regulation at unity power factor is being estimated. For low power factors, its effect is negligible in practically all cases. If

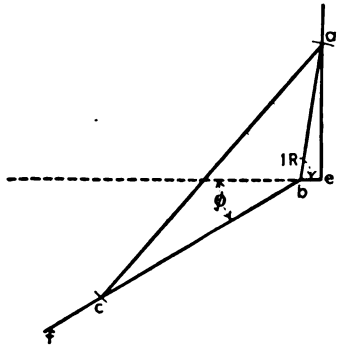

FIG. 2

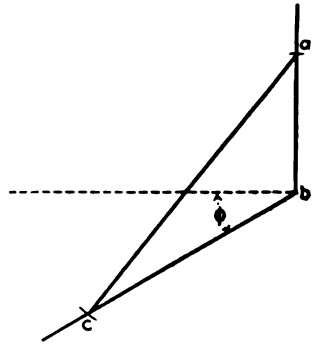

FIG. 3

resistance is neglected, the simpler e.m.f. diagram, Fig. 3, may be used to obtain points on the load saturation curve for the power factor under consideration.

586 Method c.

Where it is not possible to obtain by test a zero-power-factor saturation curve as in Method b, this curve can be estimated closely from open-circuit and short-circuit curves, by reference to tests at zero power factor on other machines of similar magnetic circuit. Having obtained the estimated zero-power-factor curve, the load saturation for any other power factor is obtained as in method b.

Thus Method c is the same as Method b; except that the zero-power-factor curve must be estimated. This may be done as follows. In Fig. 4, OA is the open-circuit saturation curve and OE the short-circuit line as shown by test. The zero-power-factor curve corresponding to any given current BF will start from point B, and for machines designed with low saturation and low reactance, will follow parallel to OA, as shown by the dotted curve BD, which is OA shifted horizontally parallel to itself by the distance OB. In high-speed machines, or in others

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having low reactance and a low degree of saturation in the magnetic circuit the zero-power-factor curve will lie quite close to *BD*, particularly in those parts that are used for determining the regulation. This is the case with many turbo-generators and high-speed water-wheel generators. In many cases, however, the zero-power-factor curve will deviate from *BD*, as shown by *BC*, and the deviation will be most pronounced in machines of high reactance, high saturation, and large magnetic leakage. The position of the actual curve *BC* with relation to *BD*, can be approximated with sufficient exactness by investigating the corresponding relation as obtained by test at zero power factor on machines of similar characteristics and magnetic circuit. Or curve *BC* can be calculated by methods based on the results of tests at zero power factor. After *BC* has been obtained, the saturation curve and regulation for any other power factor can be derived as in Method (b).

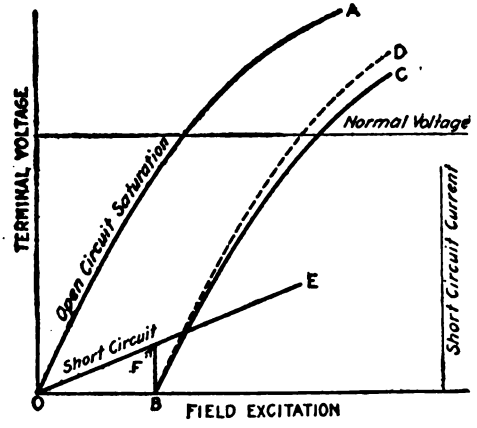

FIG. 4

587 Tests and Computation of Regulation for Constant-Potential Transformers.

The regulation can be determined by loading the transformer and measuring the change in voltage with change in load, at the specified power factor. This method is not generally applicable for shop tests, particularly on large transformers.

The regulation for any specified load and power factor can be computed from the measured impedance watts and impedance volts, as follows:

Let:

P = impedance watts, as measured in the short-circuit test and corrected to 75°C.

E_s = impedance volts, as measured in the short-circuit test.

IX = Reactance Drop in Volts.

I = Rated Primary Current.

E = Rated Primary Voltage.

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q_r = percent drop in phase with current.
q_x = percent drop in quadrature with current.

$$IX = \sqrt{E_s^2 - \left(\frac{P}{I}\right)^2}$$

$$q_r = 100\frac{P}{EI}$$

$$q_x = 100\frac{IX}{E}$$

588 Then—

1. For **unity power factor**, we have approximately:-

$$\text{Per cent regulation} = q_r + \frac{q_x^2}{200}$$

589 2. For **inductive loads** of power-factor m and reactive-factor n,

$$\text{Per cent regulation} = mq_r + nq_x + \frac{(mq_x - nq_r)^2}{200}$$

TRANSFORMER CONNECTIONS*

(*These rules do not apply to auto transformers.*)

600 **Diagrammatic Sketch of Connections.** The manufacturer shall furnish with each transformer a complete diagrammatic sketch of the internal connections, and all terminals and taps of the transformer shall be marked to correspond with letters and numbers in the sketch. This sketch should preferably be on a metal plate on the transformer case.

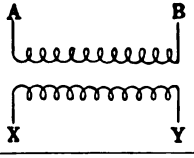
SINGLE-PHASE TRANSFORMERS

601 **Marking of Leads.** The leads of single-phase transformers shall be distinguished from each other by marking the high-voltage leads with the letters A and B, and the low-voltage leads with the letters X and Y.

The terminals (by terminals is meant the ends of the windings) shall be so marked that the potential difference in all windings at any instant shall have the same sign, that is, the potential difference between A and B shall have the same sign at any instant as the potential difference between X and Y.**

602 In accordance with the above rule, the terminals of single-phase transformers shall be marked as follows:

(1) High- and Low-Voltage Windings in Phase:



*Sections **601** to **611**, relative to a specific scheme of marking the leads, are tentative only, subject to the adoption of a comprehensive scheme of marking the terminals of all classes of apparatus.

**To test the correctness of single-phase markings, connect A to X and apply voltage to the high voltage winding A-B. Voltage B-Y must be numerically less than voltage A-B.

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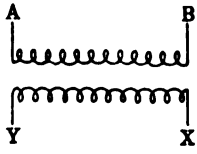
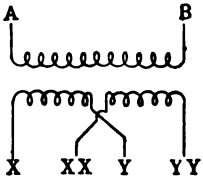
603 (2) High- and Low-Voltage Windings 180 deg. Apart in Phase:

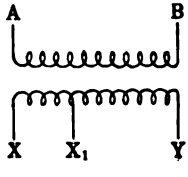


604 Single-Phase Transformers with More than Two Windings. Transformers with three or more windings (each being provided with separate outgoing leads) shall have the leads of two of their windings lettered in accordance with the preceding paragraph. The remaining leads shall be designated AA BB, etc. in the case of high-voltage leads and XX, YY, etc. in the case of low-voltage leads. For example, transformers having four secondary leads from two distinct, similar windings shall be lettered as follows:



This indicates that the low-voltage winding consists of two disconnected parts, one part having terminals X, Y and the other part having terminals XX, YY. For multiple connection, X and XX are to be connected and Y and YY are to be connected. For series operation, Y is to be connected to XX.

605 Tap Connections. All tap connections which are not brought outside the transformer case shall be marked serially with numerals only. Where tap leads are brought out of the transformer case they shall be given the letter designation together with a subscript indicating the relative position of the tap, as in the following diagram.



606 Neutral Lead. Where a neutral lead is brought outside the transformer case, it shall be lettered N.

607 Parallel Operation. Transformers marked as above may be operated in parallel, by connecting similarly marked terminals provided their ratios, voltages resistances and reactances are such as to permit parallel operation.

THREE-PHASE TRANSFORMERS

608 Marking of Leads. Three-phase transformers ordinarily have three or four leads for high-voltage and three or four leads for low-

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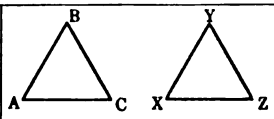
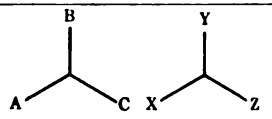
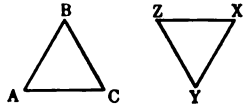
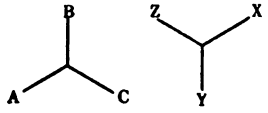
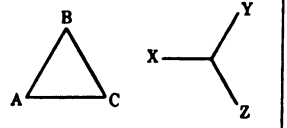
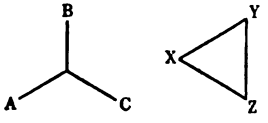
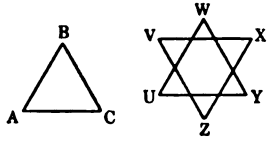
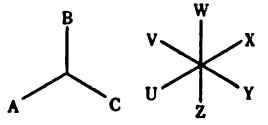
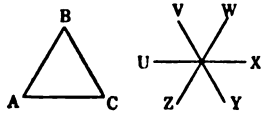
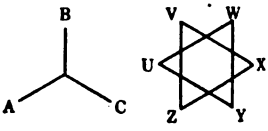
voltage windings. To distinguish the various leads from each other, and also to distinguish between the various phase relations obtainable, the three high-voltage leads should be lettered A, B and C and the three low-voltage leads X, Y and Z.

For transformers having six-phase secondaries the primary leads should be lettered A, B and C as above, and the secondary leads U, V, W, X, Y and Z.

The letters shall be so applied to the transformer terminals that if the phase sequence of voltage on the high-voltage side is in the order of A to B to C, it is in the order of X to Y to Z, etc., on the low-voltage side. This arrangement is represented by the diagrams below, which show the various common angular displacements between high- and low-voltage windings of standard transformers. In addition it should be distinctly stated, preferably on the rating plate, in which of the groups given in the following diagrams the transformer belongs.

THREE PHASE TRANSFORMERS		
GROUP-1 Angular Displacement 0°		
GROUP-2 Angular Displacement 180°		
GROUP-3 Angular Displacement 30°		

SIX PHASE TRANSFORMERS		
GROUP-4 Angular Displacement 0°		
GROUP-5 Angular Displacement 30°		

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609 The rules given above for single-phase transformers in regard to the neutral tap (see **§606**), and also in regard to internal connections (see **§§601** to **605**), are applicable to three-phase transformers and six-phase transformers.

610 **Angular Displacement.** The angular displacement between high- and low-voltage windings, is the angle in the diagram in **§608** between the lines passing from the neutral point through *A* and *X* respectively for three-phase transformers and through *A* and *U* for six-phase transformers. Thus, in Group **1**, the angular displacement is zero degrees; in Group 2, the angular displacement is 180° and in Group 3, the angular displacement is 30°.

611 **Parallel Operation.** Three-phase and six-phase transformers marked as above may be operated in parallel, by connecting similarly marked terminals together, provided their ratios, voltages, resistances, reactances and angular displacements are such as to permit parallel operation.

INFORMATION ON THE RATING PLATE OF A MACHINE

620 It is recommended that the rating plate of machines which comply with the Institute rules shall carry a distinctive special sign, such as "A.I.E.E. 1916 Rating" or "A16" Rating.

621 The absence of any statement to the contrary on the rating plate of a machine implies that it is intended for continuous service and for the standard altitude and ambient temperature of reference. See **§§287, 305, 308** and **309.**

622 The rating plate of a machine intended to work under various kinds of rating must carry the necessary information in regard to those kinds of ratings.

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STANDARDS FOR WIRES AND CABLES

TERMINOLOGY*

635 **Wire.**—A slender rod or filament of drawn metal.

The definition restricts the term to what would ordinarily be understood by the term "solid wire." In the definition, the word "slender" is used in the sense that the length is great in comparison with the diameter. If a wire is covered with insulation, it is properly called an insulated wire; while primarily the term "wire" refers to the metal, nevertheless when the context shows that the wire is insulated, the term "wire" will be understood to include the insulation.

636 **Conductor.**—A wire or combination of wires not insulated from one another, suitable for carrying a single electric current.

The term "conductor" is not to include a combination of conductors insulated from one another, which would be suitable for carrying several different electric currents.

Rolled conductors (such as busbars) are, of course, conductors, but are not considered under the terminology here given.

637 **Stranded Conductor.**—A conductor composed of a group of wires, or of any combination of groups of wires.

The wires in a stranded conductor are usually twisted or braided together.

638 **Cable.**—(1) A stranded conductor (single-conductor cable); or (2) a combination of conductors insulated from one another (multiple-conductor cable).

The component conductors of the second kind of cable may be either solid or stranded, and this kind of cable may or may not have a common insulating covering. The first kind of cable is a single conductor, while the second kind is a group of several conductors. The term "cable" is applied by some manufacturers to a solid wire heavily insulated and lead-covered; this usage arises from the manner of the insulation, but such a conductor is not included under this definition of "cable." The term "cable" is a general one, and, in practise, it is usually applied only to the larger sizes. A small cable is called a "stranded wire" or a "cord," both of which are defined below. Cables may be bare or insulated, and the latter may be armored with lead, or with steel wires or bands.

639 **Strand.**—One of the wires, or groups of wires, of any stranded conductor.

640 **Stranded Wire.**—A group of small wires, used as a single wire.

A wire has been defined as a slender rod or filament of drawn metal. If such a filament is subdivided into several smaller filaments or strands, and is used as a single wire, it is called a "stranded wire." There is no sharp dividing line of size between a "stranded wire" and a "cable." If used as a wire, for example in winding inductance coils or magnets, it is called a stranded wire and not a cable. If it is substantially insulated, it is called a "cord," defined below.

*From Circular No. 37 of the Bureau of Standards.

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641 **Cord.**—A small cable, very flexible and substantially insulated to withstand wear.

There is no sharp dividing line in respect to size between a "cord" and a "cable," and likewise no sharp dividing line in respect to the character of insulation between a "cord" and a "stranded wire." Rubber is used as the insulating material for many classes of cords.

642 **Concentric Strand.**—A strand composed of a central core surrounded by one or more layers of helically-laid wires or groups of wires.

643 **Concentric-Lay Cable.**—A single-conductor cable composed of a central core surrounded by one or more layers of helically-laid wires.

644 **Rope-Lay Cable.**—A single-conductor cable composed of a central core surrounded by one or more layers of helically-laid groups of wires.

This kind of cable differs from the preceding in that the main strands are themselves stranded.

645 **N-Conductor Cable.**—A combination of N conductors insulated from one another.

It is not intended that the name as here given be actually used. One would instead speak of a "3-conductor cable," a "12-conductor cable" etc. In referring to the general case, one may speak of a "multiple-conductor cable" (as in definition §638 above.)

646 **N-Conductor Concentric Cable.**—A cable composed of an insulated central conducting core with $(N-1)$ tubular stranded conductors laid over it concentrically and separated by layers of insulation.

This kind of cable usually has only two or three conductors. Such cables are used in carrying alternating currents. The remark on the expression "N-conductor" given for the preceding definition applies here also.

647 **Duplex Cable.**—Two insulated single-conductor cables, twisted together.

They may or may not have a common insulating covering.

648 **Twin Cable.**—Two insulated single-conductor cables laid parallel, having a common covering.

649 **Triplex Cable.**—Three insulated single-conductor cables twisted together.

They may or may not have a common insulating covering.

650 **Twisted Pair.**—Two small insulated conductors, twisted together, without a common covering.

The two conductors of a "twisted pair" are usually substantially insulated, so that the combination is a special case of a "cord."

651 **Twin Wire.**—Two small insulated conductors laid parallel, having a common covering.

SPECIFICATION OF SIZES OF CONDUCTORS

652 **The sizes of solid wires** shall be stated by their diameter in mils, the American Wire Gage (Brown and Sharpe) sizes being taken as standard. The sizes of stranded conductors shall be stated by their cross-sectional area in circular mils. For brevity, in cases where the most

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careful specification is not required, the sizes of solid wires may be stated by the gage number in the American Wire Gage, and the sizes of stranded conductors smaller than 250,000 circular mils (*i.e.*, No. 0000 A.W.G. or smaller) may likewise be stated by means of the gage number in the American Wire Gage of a solid wire having the same cross-sectional area. Futhermore, an exception is made in the case of " Flexible Stranded Conductors," for which see §655 below. In stating large cross-sections, it is sometimes convenient to use a circular inch (507 sq. mm.) instead of 1,000,000 circular mils.

STRANDING

653 Cables not requiring special flexibility shall be stranded in accordance with the following table.

TABLE XII

Standard Stranding of Concentric Lay-Cables

SIZE (See note 1.)	Number of Wires (See note 2)	
	A Bare, insulated or weather-proof cables for aerial use.	B Insulated cables for other than aerial use.
2.0 Cir. Inches	91	127
1.5 "	61	91
1.0 "	61	61
0.6 "	37	61
0.5 "	37	37
0.4 "	19	37
0000 A. W. G.	19 or 7 (See note 3.)	19
00 "	7	19
2 "	7	7
7 and smaller	..	7

1. For intermediate sizes, use stranding for next larger size.
2. Conductors of 0000 A. W. G. and smaller are often made solid and this table of stranding should not be interpreted as excluding this practice.
3. Class A cable, sizes 0000 and 000 A. W. G., is usually made of 7 strands when bare and 19 strands when insulated or weatherproof.

654 Sectional Area of Cables. The cross-sectional area of a cable shall be considered to be the sum of the cross-sectional areas of its component wires, when measured perpendicular to their axes.

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655 Flexible Stranding. Conductors of special flexibility should ordinarily be made with wires of regular A.W.G. sizes,* the number of wires and size being given. The approximate gage number or approximate circular mils of such flexible stranded conductors may be stated. The stranding of standard flexible cables is given in Table XIII and a tentative stranding for apparatus cable in Table XIII-A.

TABLE XIII

Proposed Standard Stranding of Flexible Cables

Nearest A.W.G. size (see Note 1)	Circular mils (see Note 3)	Diam. of cable. Mils	No. of wires	Size of each wire A.W.G.	Diam. Mils	Make-up (see Note 2)
..	2039000	1836.	703	15.5	53.9	37 × 19
..	1816000	1778.	"	16.0	50.8	"
..	1617000	1680.	"	16.5	48.0	"
..	1440000	1586.	"	17.0	45.3	"
..	1282000	1495.	"	17.5	42.7	"
..	1103000	1372.	427	16.0	50.8	61 × 7
..	874500	1223.	"	17.0	45.3	"
..	693400	1088.	"	18.0	40.3	"
..	550000	969.	"	19.0	35.9	"
..	436400	864.	"	20.0	32.0	"
..	345900	770.	"	21.0	28.5	"
..	274300	686.	"	22.0	25.4	"
..	264700	672.	259	20.0	32.0	37 × 7
0000	209800	599.	"	21.0	28.5	"
000	171300	539.	133	19.0	35.9	19 × 7
00	135900	480.	"	20.0	32.0	"
0	107700	428.	"	21.0	28.5	"
1	82780	332.	91	20.5	30.2	Concentric
2	65660	296.	"	21.5	26.9	"
3	58460	279.	"	22.0	25.4	"
4	39190	229.	61	22.0	25.4	"
5	31080	203.	"	23.0	22.6	"
6	24650	181.	"	24.0	20.1	"
8	17400	152.	"	25.5	16.9	"
10	10560	118.	37	25.5	16.9	"
12	6442	94.	"	27.5	13.4	"
14	4177	74.	"	29.5	10.6	"
Smaller	....	....	To equal Required Size	30.0	....	Bunched

NOTE 1. The A.W.G. sizes except for 61 strands are approximated within 2 per cent. In the case of 61 strand cables the approximation is 6 per cent.

NOTE 2. "61 × 7" signifies a rope-lay cable composed of 61 strands of 7 wires each.

NOTE 3. Circular mils are based on theoretical diameters of A.W.G. sizes which vary above or below values given in table by less than 0.1 mil.

*Where necessary to closely approximate a regular size cable, the strands may be made of half-size wires from No. 15 to No. 30 A. W. G.

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TABLE XIII-A

Proposed Standard Stranding of Apparatus Cables

(This table is offered for consideration but will not be recommended for final adoption until ratified by other societies interested.)

Nearest A.W.G. size (see Note 1)	Circular mils (see Note 3)	Diameter of cable Mils	No. of wires	Size of each wire A.W.G	Diam. Mils	Make-up
..	2053000	1903.	2257	20.5	30.2	61 × 37
..	1829000	1796.	"	21.0	28.5	"
..	1629000	1695.	"	21.5	26.9	"
..	1450000	1600.	"	22.0	25.4	"
..	1291000	1506.	"	22.5	23.9	"
..	1150000	1424.	"	23.0	22.6	"
..	1054000	1359.	1159	20.5	30.2	61 × 19
..	938900	1283.	"	21.0	28.5	"
..	836200	1211.	"	21.5	26.9	"
..	744500	1143.	"	22.0	25.4	"
..	663000	1076.	"	22.5	23.9	"
..	590500	1017.	"	23.0	22.6	"
..	525800	958.	"	23.5	21.3	"
..	451600	889.	703	22.0	25.4	37 × 19
..	402200	836.	"	22.5	23.9	"
..	358200	791.	"	23.0	22.6	"
..	319000	745.	"	23.5	21.3	"
..	284000	703.	"	24.0	20.1	"
..	253000	665.	"	24.5	19.0	"
0000	217600	610.	427	23.0	22.6	61 × 7
000	172500	543.	"	24.0	20.1	"
00	136800	483.	"	25.0	17.9	"
0	104600	422.	259	24.0	20.1	37 × 7
1	82980	376.	"	25.0	17.9	"
2	65810	334.	"	26.0	15.9	"
3	52190	298.	"	27.0	14.2	"
4	42610	268.	133	25.0	17.9	19 × 7
5	33800	238.	"	26.0	15.9	"
6	26800	213.	"	27.0	14.2	"
see Note 2.						

NOTE 1. The A.W.G. sizes are approximated within 3 per cent.

NOTE 2. For sizes smaller than No. 6 see table XIII.

NOTE 3. Circular mils are based on theoretical diameters of A.W.G. sizes, which vary above or below values given in table by less than 0.1 mil.

656 **Correction for Lay.** The resistance and mass of a stranded conductor are greater than in a solid conductor of the same cross-sectional area, depending on the lay (*i.e.*, the pitch of the twist of the wires). Two per cent shall be taken as the standard increment of resistance and of mass. In cases where the lay is definitely known, the increment should be calculated and not assumed.

The direction of lay is the lateral direction in which the strands of a cable run over the top of the cable as they recede from an observer looking along the axis of the cable.

657 The lay of any layer of wires of a cable or strand shall not exceed 15 times the pitch diameter of that layer. The lay of any layer of

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strands of rope-lay cables shall not exceed 12 times the pitch diameter of the layer.

CONDUCTIVITY OF COPPER.

675 The following I. E. C. rules are adopted:*

The following shall be taken as normal values for standard annealed copper:

(1) At a temperature of 20°C., the resistance of a wire of standard annealed copper one meter in length and of a uniform section of 1 square millimeter is 1/58 ohm = 0.017241.... ohm.

(2) At a temperature of 20°C., the density of standard annealed copper is 8.89 grams per cubic centimeter.

(3) At a temperature of 20°C, the "constant mass" temperature coefficient of resistance of standard annealed copper, measured between two potential points rigidly fixed to the wire, is 0.00393 = 1/254.45.... per degree centigrade.

(4) As a consequence, it follows from (1) and (2) that, at a temperature of 20 °C. the resistance of a wire of standard annealed copper of uniform section, one meter in length and weighing one gram, is (1/58) × 8.89 = 0.15328..... ohm.†§

676 **Copper Wire Tables.** The copper-wire Tables published by the Bureau of Standards in Circular No. 31 are adopted. These Tables are based upon the I. E. C. rules stated in §675.

HEATING AND TEMPERATURE OF CABLES.

677 **Maximum Safe Limiting Temperatures.**

The maximum safe limiting temperature in degrees C. at the surface of the conductor in a cable shall be:—

For impregnated paper insulation	(85—E)
" varnished cambric	(75—E)
" rubber insulation	(60—0.25E)

where E represents the r.m.s. operating e.m.f. in kilovolts between conductors.

Thus, at a working pressure of 3.3 kv., the maximum safe limiting temperature at the surface of the conductor, or conductors, in a cable would be:—

For impregnated paper	81.7°C.
" varnished cambric	71.7°C.
" rubber insulation	59.2°C.

ELECTRICAL TESTS.

678 **Lengths Tested.** Electrical tests of insulation on wires and cables shall be made on the entire lengths to be shipped.

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*See I. E. C. Publication No. 28 "International Standard of Resistance for Copper" March 1914.

†Paragraphs (1) and (4) of § 675 define what are sometimes called "volume resistivity," and "Mass resistivity" respectively. This may be expressed in other units as follows:—volume resistivity = 1.7241 microhms-cm. (or microhms in a cm. cube) at 20°C. = 0.67879 microhm-inch at 20°C., and mass resistivity = 875.20 ohms (mile, pound) at 20°C.

§For detailed specifications of commercial copper, see the "Standard Specifications" of the American Society for Testing Materials.

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679 **Immersion in Water.** Electrical tests of insulated conductors not enclosed in a lead sheath, shall be made while immersed in water after an immersion of twelve (12) consecutive hours, if insulated with rubber compound, or if insulated with varnished cambric. It is not necessary to immerse in water insulated conductors enclosed in a lead sheath.

In multiple-conductor cables, without waterproof overall jacket of insulation, no immersion test should be made on finished cables, but only on the individual conductors before assembling.

680 **Dielectric-Strength Tests. Object of Tests.** Dielectric tests are intended to detect weak spots in the insulation and to determine whether the dielectric strength of the insulation is sufficient for enabling it to withstand the voltage to which it is likely to be subjected in service, with a suitable factor of assurance.

The initially-applied voltage must not be greater than the working voltage, and the rate of increase shall not be over 100 per cent in 10 seconds.

681 **Factor of Assurance.** The factor of assurance of wire or cable insulation shall be the ratio of the voltage at which it is tested to that at which it is used.

682 **Test Voltage.** The dielectric strength of wire and cable insulation shall be tested at the factory, by applying an alternating test voltage between the conductor and sheath or water.

683 **The Magnitude and Duration of the Test Voltage** should depend upon the dielectric strength and thickness of the insulation, the length and diameter of the wire or cable, and the assurance factor required, the latter in turn depending upon the importance of the service in which the wire or cable is employed.

684 **The following test voltages** shall apply unless a departure is considered necessary, in view of the above circumstances. Rubber covered wires or cable for voltages up to 7 kv. shall be tested in accordance with the National Electric Code. Standardization for higher voltages for rubber insulated cables is not considered possible at the present time.

Varnished cambric and impregnated paper insulated wires or cables shall be tested at the place of manufacture for five (5) minutes in accordance with the Table XIV below.

TABLE XIV

Recommended Test Kilovolts Corresponding to Operating Kilovolts

Operating kv.	Test kv.	Operating kv.	Test kv.
Below 0.5	2.5*	5	14
0.5	3	10	25
1	4	15	3
2	6.5	20	44
3	9	25	53
4	11.5		

*The minimum thickness of insulation shall be $\frac{1}{16}$ in. (1.6 mm.)

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Different engineers specify different thickness of insulation for the same working voltages. Therefore, at the present time the test kv. corresponding to working kv. given in Table XIV are based on the **minimum** thickness of insulation specified by engineers and operating companies.†

685 **The Frequency of the Test Voltage** shall not exceed 100 cycles per second, and should approximate as closely as possible to a sine wave. The source of energy should be of ample capacity.

686 **Where Ultimate Break-Down Tests** are required, these shall be made on samples not more than 6 meters (20 ft.) long. The maximum allowable temperature at which the test is made for the particular type of insulation and the particular working pressure, shall not be greater than the temperature limits given in **§ 677**.

687 **Multiple-Conductor Cables.** Each conductor of a multiple-conductor cable shall be tested against the other conductors connected together with the sheath or water.

INSULATION RESISTANCE

688 **Definition.** The insulation resistance of an insulated conductor is the electrical resistance offered by its insulation, to an impressed voltage tending to produce a leakage of current through the same.

689 **Insulation Resistance** shall be expressed in megohms for a specified length (as for a kilometer, or a mile, or one thousand feet), and shall be corrected to a temperature of 15.5° C. using a temperature coefficient determined experimentally for the insulation under consideration.

690 **Linear Insulation Resistance,** or the insulation resistance of Unit Length, shall be expressed in terms of the megohm-kilometer, or the megohm-mile, or the megohm-thousand-feet.

691 **Megohms Constant.** The Megohms Constant of an insulated conductor shall be the factor " K " in the equation

$$R = K \log_{10} \frac{D}{d}$$

where R = The insulation resistance, in megohms, for a specified unit length.

D = Outside diameter of insulation.

d = Diameter of conductor.

Unless otherwise stated, K will be assumed to correspond to the mile unit of length.

692 **Test.** The apparent insulation resistance should be measured after the dielectric-strength test, measuring the leakage current after a one-minute electrification, with a continuous e.m.f. of from 100 to 500 volts, the conductor being maintained negative to the sheath or water.

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†The Standards Committee does not commit itself to the principle of basing test voltages on working voltages, but it is not yet in possession of sufficient data to base them upon the dimensions and physical propertis of the insulation.

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693 **Multiple-Conductor Cables.** The insulation resistance of each conductor of a multiple-conductor cable shall be the insulation resistance measured from such conductor to all the other conductors in multiple with the sheath or water.

CAPACITANCE OR ELECTROSTATIC CAPACITY

694 **Capacitance** is ordinarily expressed in microfarads. Linear Capacitance, or Capacitance per unit length, shall be expressed in Microfarads per unit length (kilometer, or mile, or one thousand feet) and shall be corrected to a temperature of 15.5° C.

695 **Microfarads Constant.** The Microfarads Constant of an insulated conductor shall be the factor " K " in the equation

$$C = \frac{K}{\text{Log}_{10}\frac{D}{d}}$$

where C = the capacitance in microfarads per unit length.

D = the outside diameter of insulation.

d = the diameter of conductor.

Unless otherwise stated, K will be assumed to refer to the mile unit of length.

696 **Measurement of Capacitance.** The Capacitance of low-voltage cable, shall be measured by comparison with a standard condenser. For long lengths of high-voltage cables, where it is necessary to know the true capacitance, the measurement should be made at a frequency approximating the frequency of operation.

697 **Paired Cables.** The capacitance shall be measured between the two conductors of any pair, the other wires being connected to the sheath or ground.

698 **Electric Light and Power Cables.** The capacitance of low-voltage cables is generally of but little importance. The capacitance of high-voltage cables should be measured between the conductors, and also between each conductor and the other conductors connected to the lead sheath or ground.

699 **Multiple-Conductor Cables** (not paired). The capacitance of each conductor of a multiple-conductor cable shall be the capacitance measured from such conductor to all of the other conductors in multiple with the sheath or the ground.

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STANDARDS FOR SWITCHES AND OTHER CIRCUIT-CONTROL APPARATUS*

SWITCHES

720 **The following Rules apply to Switches** of above 600 volts. (For 600 volts and below, see National Electric Code.†)

721 **Definition.** A switch is a device for making, breaking, or changing connections in an electric circuit.

722 **Rating.**

(a) By amperes to be carried with not more than 30 °C. rise on contacts and current-carrying parts.

(b) By normal voltage of circuit on which it may be used.

723 **Performance and Tests.**

(a) **Heating Test** with rated current applied continuously until temperature is constant; ambient temperature 40 °C.

(b) **Dielectric Test** at 2½ times rated voltage plus 2000. **See §509.**

CIRCUIT BREAKERS

724 **Definition.** A device designed to open a current-carrying circuit without injury to itself. A circuit breaker‡ may be:

(a) An automatic circuit-breaker, which is designed to trip automatically under any predetermined condition of the circuit, such as an underload or overload of current or voltage.

(b) A manually tripped circuit-breaker, which is designed to be tripped by hand.

Both types of operation may be combined in one and the same device.

725 **Rating.**

(a) By normal current-carrying capacity.

(b) By normal voltage.

(c) By amperes which it can interrupt at normal voltage of the circuit.

726 **Performance and Tests.** The heating test shall be made with normal current. In oil circuit breakers the same oil must be used for heating tests as for rupturing tests. The rise of temperature at the contacts shall not exceed 30 °C. The Rise on tripping solenoids and accessory parts not to exceed 50 °C. Ambient temperature of reference, 40 °C.

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*These rules do not apply to magnetically-operated or air-operated switches used for motor control.

†By the term "Code" is meant "National Electrical Code" as recommended by the National Fire Protection Association.

‡These rules refer only to circuit breakers of above 550 volts. For 550 volts and below, see the National Electric Code.

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727 **Dielectric Test.** Same as **§723.**

728 **Rupturing Test** must be made with the current specified under **§725** (c), and at normal voltage.

NOTE. Although circuit breakers should be considered as devices alone, no account being taken, in the rating, of the system on which they are to be used: yet in applying circuit breakers to any given service, it may be necessary to take into account the system on which they are to be used, with all its characteristics.

Allowances must be made for the reactance, resistance, etc., of the circuit to be controlled, as these have a direct bearing on the maximum current flow.

In some systems it has been found that the pressure rises so high during switching, that higher insulation tests than that specified in **§723** should be given.

FUSES

(For circuits up to and including 600 volts, see National Electric Code)

729 **Definition.** A fuse is an element designed to melt or dissipate at a predetermined current value, and intended to protect against abnormal conditions of current.

NOTE. (The terminals, tubes, etc. which go with the fuse proper are included in the definition).

730 **Rating.** Fuses shall be rated at the maximum current which they are required to carry continuously, and at the normal voltage of the circuit on which they are designed to be used.

Fuses may be divided into two classes:

(1) Those designed to protect the circuit and apparatus both against short circuit and against definite amounts of overload (*e.g.* fuses of the National Electric Code which open on 25 per cent overload).

(2) Those designed to protect the system only against short circuits; (*e.g.* expulsion fuses, which blow at several times the current which they are designed to carry continuously). The line separating these two classes is not definitely fixed.

731 **Temperature.** Coils or windings (such as accompany fuses of the magnetic blow-out type) should not exceed the limits set for machine coils having the same character of insulation. (See **§§376** to **379**). The highest temperature for the fuse proper should not exceed the safe limit for the material employed (*e.g.* the temperature of the fibre tube of an enclosed fuse should not exceed the safe limit for this material, but an open-link metal fuse may be run at any temperature which will not injure the fuse material; except that no application of the above rule shall contravene the National Electric Code).

732 **Test.** For fuses intended for use on circuits of small capacity, or in protected positions on systems of large capacity, see Nation-

NOTE. Complete standardization of these fuses above 600 volts, according to the method of the National Electric Code, is not advisable at this time, but is expected to be accomplished by an eventual extension of the National Electric Code. Until such extension is made, the following definitions and ratings may be followed.

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al Electric Code. For large power fuses intended for service similar to that required of circuit breakers, see §724 to 728, or the National Electric Code, as far as the latter applies.

LIGHTNING ARRESTERS

733 Definition. A lightning arrester is a device for protecting circuits and apparatus against lightning or other abnormal potential rises of short duration.

734 Rating. Arresters shall be rated by the voltage of the circuit on which they are to be used.

Lightning arresters may be divided into two classes:

(a) Those intended to discharge for a very short time.

(b) Those intended to discharge for a period of several minutes.

735 Performance and Tests. Dielectric Test same as §723.

The resistance of the arrester at double potential and also at normal potential, shall be determined by observing the discharge currents through the arrester.

(c) In the case of any arrester using a gap, a test shall be made of the spark potential on either direct-current or 60-cycle a-c. excitation.

(d) The equivalent sphere gap under disruptive discharge shall also be measured, using a considerable quantity of electricity.

(e) The endurance of the arrester to continuous surges shall be tested.

PROTECTIVE REACTORS

736 Definition. A reactor (See §82 and 214) is a device for protecting circuits by limiting the current flow and localizing the disturbance under short-circuit conditions.

737 Rating.

(a) In kilovolt-amperes absorbed by normal current.

(b) By the normal current, frequency and line (delta) voltage for which the reactor is designed.

(c) By the current which the device is required to stand under short-circuit conditions.

738 Performance and Tests.

The Heat Test shall be made with normal current and frequency applied until the temperature is constant. The temperature should not exceed the safe limits for the materials employed. See §§376 to 379.

739 Dielectric Test. 2½ times line voltage plus 2000, for one minute, from conductor to ground.

NOTE. The reactor shall be so designed as to be capable of withstanding, without mechanical injury, rated current at normal frequency, suddenly applied.

RESISTOR OR RHEOSTAT

740 Definition. Any device heretofore commonly known as a resistance, used for operation or control. (§81) See National Electric Code.

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INSTRUMENT TRANSFORMERS

741 Definition. An instrument transformer is a transformer for use with measuring instruments, in which the conditions in the primary circuit as to current and voltage are represented with high numerical accuracy in the secondary circuit.

Under this heading and for more general use:

(a) A current transformer is a transformer designed for series connection in its primary circuit with the ratio of transformation appearing as a ratio of currents.

(b) A potential (voltage) transformer is a transformer designed for shunt or parallel connection in its primary circuit, with the ratio of transformation appearing as a ratio of potential differences (voltages).

For further definitions relative to instrument transformers, see 205-207.

For the dielectric test of potential transformers, see §500, and for the dielectric test of current transformers, see §509.

Further standards concerning instrument transformers are still under discussion.

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STANDARDS FOR ELECTRIC RAILWAYS

DEFINITIONS

760 **Transmission System:** When the current generated for an electric railway is changed in kind or voltage, between the generator and the cars or locomotives, that portion of the conductor system carrying current of a kind or voltage substantially different from that received by the cars or locomotives, constitutes the *transmission system.**

761 **Distribution System:** That portion of the conductor system of an electric railway which carries current of the kind and voltage received by the cars or locomotives, constitutes the *distribution system.**

762 **Substation:** A substation is a group of apparatus or machinery which receives current from a transmission system, changes its kind or voltage, and delivers it to a distribution system.

RATING OF RAILWAY SUBSTATION MACHINERY

763 **Continuous Rating.** The rating of a substation machine shall be the kv-a. output at a stated power factor input, which it will deliver continuously with temperatures or temperature rises not exceeding the limiting values given in Sections **376** and **379** and also fulfilling the other requirements set forth in these rules and summarized in Section **260.**

764 **Momentary Loads.** These machines should be capable of carrying a load of twice their rating for one minute, after a continuous run at rated load, without disqualifying them for continuous service.

765 **Nominal Rating.** Where the continuous rating is inconvenient, the following nominal rating may be used. The nominal rating of a substation machine shall be the kv-a. output at a stated power factor input, which, having produced a constant temperature in the machine may be increased 50 per cent for two hours, without producing temperatures or temperature rises exceeding by more than 5°C. the limiting values given in §**376** and **379.** These machines should be capable of carrying a load of twice their nominal rating for a period of one minute, without disqualifying them for continuous service. The name plate should be marked " nominal rating."

CONDUCTOR AND RAIL SYSTEMS.

766 **Contact Conductors.** That part of the distribution system other than the traffic rails, which is in immediate electrical contact with

*These definitions are identical in sense, although not in words, with those of the Interstate Commerce Commission, as given in their Classification of Accounts for Electric Railways.

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the circuits of the cars or locomotives, constitutes the contact conductors.

767 **Contact Rail:** A rigid contact conductor.

768 OVERHEAD CONTACT RAIL: A contact rail above the elevation of the maximum equipment line.†

769 THIRD RAIL: A contact conductor placed at either side of the track, the contact surface of which is a few inches above the level of the top of the track rails.

770 CENTER CONTACT RAIL: A contact conductor placed between the track rails, having its contact surface above the ground level.

771 UNDERGROUND CONTACT RAIL: A contact conductor placed beneath the ground level.

772 GAGE OF THIRD RAIL: The distance, measured parallel to the plane of running rails, between the gage line of the nearer track rail and the inside gage line of the *contact surface* of the third rail.

773 ELEVATION OF THIRD RAIL: The elevation of the contact-surface of the third rail, with respect to the plane of the tops of running rails.

774 STANDARD GAGE OF THIRD RAILS: The gage of third rails shall be not less than 26 inches (66 cm.) and not more than 27 inches (68.6 cm.).

775 STANDARD ELEVATION OF THIRD RAILS: The elevation of third rails shall be not less than 2¾ inches (70 mm.), and not more than 3½ inches (89 mm.).

776 THIRD RAIL PROTECTION: A guard for the purpose of preventing accidental contact with the third rail.

777 **Trolley Wire:** A flexible contact conductor, customarily supported above the cars.

778 **Messenger Wire or Cable:** A wire or cable running along with and supporting other wires, cables or contact conductors.

A primary messenger is directly attached to the supporting system. A secondary messenger is intermediate between a primary messenger and the wires, cables or contact conductors.

779 **Classes of Construction:** Overhead trolley construction will be classed as *Direct Suspension* and *Messenger or Catenary Suspension*

780 DIRECT SUSPENSION: All forms of overhead trolley construction in which the trolley wires are attached, by insulating devices, directly to the main supporting system.

781 MESSENGER OR CATENARY SUSPENSION: All forms of overhead trolley construction in which the trolley wires are attached, by suitable devices, to one or more messenger cables, which in turn may be carried either in *Simple Catenary, i.e.*, by primary messengers, or in *Compound Catenary, i.e.*, by secondary messengers.

782 SUPPORTING SYSTEMS shall be classed as follows:

783 SIMPLE CROSS-SPAN SYSTEMS: Those systems having at each support a single flexible span across the track or tracks.

†The contour which embraces cross-sections of all rolling stock under all normal operating conditions.

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784 MESSENGER CROSS-SPAN SYSTEMS: Those systems having at each support two or more flexible spans across the track or tracks, the upper span carrying part or all of the vertical load of the lower span.

785 BRACKET SYSTEMS: Those systems having at each support an arm or similar rigid member, supported at only one side of the track or tracks.

786 BRIDGE SYSTEMS: Those systems having at each support a rigid member, supported at both sides of the track or tracks.

787 STANDARD HEIGHT OF TROLLEY WIRE ON STREET AND INTERURBAN RAILWAYS: It is recommended that supporting structures shall be of such height that the lowest point of the trolley wire shall be at a height of 18 feet (5.5m.) above the top of rail under conditions of maximum sag, unless local conditions prevent. On trackage operating electric and steam road equipment and at crossings over steam roads, it is recommended that the trolley wire shall be not less than 21 feet (6.4m.) above the top of rail, under conditions of maximum sag.

RAILWAY MOTORS

RATING

800 **Nominal Rating**: The nominal rating of a railway motor shall be the mechanical output at the car or locomotive axle, measured in kilowatts, which causes a rise of temperature above the surrounding air, by thermometer, not exceeding 90 °C. at the commutator, and 75 °C. at any other normally accessible part after one hour's continuous run at its rated voltage (and frequency in the case of an alternating-current motor) on a stand with the motor covers arranged to secure maximum ventilation without external blower. The rise in temperature as measured by resistance, shall not exceed 100 °C.*

801 The statement of the nominal rating shall also include the corresponding voltage and armature speed.

802 **Continuous Rating:** The continuous ratings of a railway motor shall be the *inputs* in amperes at which it may be operated continuously at ½, ¾ and full voltage respectively, without exceeding the specified temperature rises (see §805), when operated on stand test with motor covers and cooling system, if any, arranged as in service. Inasmuch as the same motor may be operated under different conditions as regards ventilation, it will be necessary in each case to

* This definition differs from that in the 1911 edition of the Rules, principally by the substitution of a kilowatt rating for the horse-power rating and the omission of a reference to a room temperature of 25°C. For the purposes of these Rules the horse-power shall be taken as 746.0 watts. On account of the hitherto prevailing practise of expressing mechanical output in horse-power, it is recommended that, for the present the capacity be expressed both in kilowatts and in horse-power, a double rating, namely,

kw.————————approx. equiv. h.p.————————

In order to lay stress upon the preferred future basis, it is desirable that on rating plates, the rating in kilowatts shall be shown in larger and more prominent characters than the capacity in horse power.

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define the system of ventilation which is used. In case motors are cooled by external blowers, the flow of air on which the rating is based shall be given.

803 **Maximum Input.** The subject of momentary loads for railway motors is under investigation.

TEMPERATURE LIMITATIONS

804 **The allowable temperature** in any part of a motor in service will be governed by the kind of material with which that part is insulated. In view of space limitations, and the cost of carrying dead weight on cars, it is considered good practice to operate railway motors for short periods at higher temperatures than would be advisable in stationary motors. The following temperatures are permissible:

TABLE XV
Operating Temperatures of Railway Motors

Class of Material See §376 to 379.	Maximum Observable Temperature of windings when in continuous service.	
	By Thermometer See §345	By Resistance
A	85	110
B	100	130

For infrequent occasions, due to extreme ambient temperatures, it is permissible to operate at 15° higher temperature.

805 With a view to not exceeding the above temperature limitations, the continuous ratings shall be based upon the **temperature rises** tabulated below:

TABLE XVI
Stand-Test Temperature Rises of Railway Motors*

Class of Material See §376 to 379	Temperature Rises of windings	
	By Thermo-meter See §345	By Resis-tance
A	65	85
B	80	105

*The temperature rise in service may be very different from that on stand test. See § 1104 for relation between stand test and service temperatures, as affected by ventilation.

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806 **Field-Control Motors.** The nominal and continuous ratings of field-control motors shall relate to their performance with the operating field which gives the maximum motor rating. Each section of the field windings shall be adequate to perform the service required of it, without exceeding the specified temperature rises.

CHARACTERISTIC CURVES

810 **The Characteristic Curves** of railway motors shall be plotted with the current as abscissas and the tractive effort, speed and efficiency as ordinates. In the case of a-c. motors, the power factor shall also be plotted as ordinates.

811 **Characteristic curves of direct-current motors** shall be based upon full voltage, which shall be taken as 600 volts, or a multiple thereof.

812 **In the case of field-control motors,** characteristic curves shall be given for all operating field connections.

EFFICIENCY AND LOSSES

815 **The efficiency** of railway motors shall be deduced from a determination of the losses enumerated in **§816** to **820.** (See also **§ 1100** and **1101.**)

816 **The copper loss** shall be determined from resistance measurements corrected to 75° C.

817 **The no-load core loss, brush friction, armature-bearing friction and windage** shall be determined as a total under the following conditions:

In making the test, the motor shall be run without gears. The kind of brushes and the brush pressure shall be the same as in commercial service. With the field separately excited, such a voltage shall be applied to the armature terminals as will give the same speed for any given field current as is obtained with that field current when operating at normal voltage under load. The sum of the losses above-mentioned, is equal to the product of the counter-electromotive force and the armature current.

818 The **core loss** in d-c. motors shall be separated from the friction and windage losses above described by measuring the power required to drive the motor at any given speed without gears, by running it as a series motor on low voltage and deducting this loss from the sum of the no-load losses at corresponding speed. (See **§1101** for alternative method).

The friction and windage losses under load shall be assumed to be the same as without load, at the same speed.

The core loss under load shall be assumed as follows:

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TABLE XVII

Core Loss in D. C. Railway Motors at Various Loads.

Per cent of Input at Nominal Rating	Loss as Per cent of No-load Core Loss
200	165
150	145
100	130
75	125
50	123
25 and under	122

Note:—With motors designed for field control the core losses shall be assumed as the same for both full and permanent field. It shall be the mean between the no-load losses at full and permanent field, increased by the percentages given in the above Table.

819 **The brush-contact resistance loss** to be used in determining the efficiency, may be obtained by assuming that the sum of the drops at the contact surfaces of the positive and negative brushes is three volts.

820 The losses in gearing and axle bearings for single-reduction single-geared motors, varies with type, mechanical finish, age and lubrication. The following values, based on accumulated tests, shall be used in the comparison of single-reduction single-geared motors.

TABLE XVIII

Losses in Axle Bearings and Single-Reduction Gearing of Railway Motors.

Per Cent of Input at Nominal Rating	Losses as Per Cent of Input
200	3.5
150	3.0
125	2.7
100	2.5
75	2.5
60	2.7
50	3.2
40	4.4
30	6.7
25	8.5

Note:—Further investigation may indicate the desirability of giving separate values of the losses for full and tapped fields, or low- and high-speed motors.

ELECTRIC LOCOMOTIVES

830 **Rating.** Locomotives shall be rated in terms of the weight on drivers, nominal one-hour tractive effort, continuous tractive effort and corresponding speeds.

831 **Weight on Drivers.** The weight on drivers, expressed in pounds, shall be the sum of the weights carried by the drivers and of the drivers themselves.

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832 **Nominal Tractive Effort:** The nominal tractive effort, expressed in pounds, shall be that exerted at the rims of the drivers, when the motors are operating at their nominal (one-hour) rating.

833 **Continuous Tractive Effort.** The continuous tractive effort, expressed in pounds, shall be that exerted at the rims of the drivers when the motors are operating at their full-voltage continuous rating, as indicated in **§802**.

In the case of locomotives operating on intermittent service, the continuous tractive effort may be given for ½ or ¾ voltage, but in such cases the voltage shall be clearly specified.

834 **Speed:** The rated speed, expressed in miles per hour, shall be that at which the continuous tractive effort is exerted.

See also Appendix II on Additional Standards for Railway Motors.

RATING OF AUTOMOBILE PROPULSION MOTORS AND GENERATORS

(ROAD VEHICLES)

835 **Continuous Rating.** Automobile propulsion motors and generators shall be given a continuous rating, expressed in kilowatts output available at the shaft at specified speed. The machines shall be able to operate continuously at their rated outputs without exceeding any of the limitations referred to in **§260**.

836 **Short-Time Rating.** Owing to the variety of services which road vehicles are called upon to perform, no single standard period for short-time ratings is recommended.

837 **Nominal Rating.** No special nominal rating is required for automobile propulsion motors or generators.

838 **Temperature Rises.** Owing to space limitations and the cost of carrying dead weight on automobiles, it is considered good practice to operate the propulsion machinery at higher temperatures than would be advisable in stationary machines. The rating of automobiles motors and generators shall be based upon temperature rise, on a stand test and with motor covers arranged as in service, fifteen degrees by thermometer or twenty-five degrees by resistance, above those of **§379**.

839 **Efficiency and Losses.** Unless otherwise specified the efficiency of automobile propulsion machines shall be based upon the output at the shaft, using conventional losses as tabulated in **§440**. When such machines are of low voltage, the great influence of brush-contact losses on the efficiency requires that these losses be determined experimentally for the type of brush used.

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ILLUMINATION AND PHOTOMETRY

The following Sections, **850** to **895**, are abstracts from the rules of the Nomenclature and Standards Committee of the Illuminating Engineering Society. They are here included by permission.

850 **Luminous Flux** is radiant power evaluated according to its capacity to produce the sensation of light.

851 **The stimulus coefficient** K_λ for radiation of a particular wave-length, is the ratio of the luminous flux to the radiant power producing it.

852 **The mean value of the stimulus coefficient,** K_m, over any range of wave-lengths, or for the whole visible spectrum of any source, is the ratio of the total luminous flux (in lumens) to the total radiant power (in ergs per second, but more commonly in watts).

853 **The luminous intensity** of a point source of light is the solid angular density of the luminous flux emitted by the source in the direction considered; or it is the flux per unit solid angle from that source.

Defining equation:

Let I be the intensity, F the flux and ω the solid angle.

Then if the intensity is uniform,

$$I = \frac{F}{\omega},$$

854 **Illumination,** on a surface, is the luminous flux-density over that surface, or the flux per unit of intercepting area.

Defining equation:

Let E be the illumination and S the area of the intercepting surface.

Then when uniform,

$$E = \frac{F}{S},$$

855 **Candle,** the unit of luminous intensity maintained by the National Laboratories of France, Great Britain, and the United States.[1]

856 **Candle-power,** luminous intensity expressed in candles.

857 **Lumen,** the unit of luminous flux, equal to the flux emitted in a unit solid angle (steradian) by a point source of one candle-power.[2]

858 **Lux,** a unit of illumination equal to one lumen per square meter. The C. G. S. unit of illumination is one lumen per square centimeter. For this unit Blondel has proposed the name "Phot." One millilumen per square centimeter (milliphot) is a practical derivative of

1 This unit, which is used also by many other countries, is frequently referred to as the international candle.

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the C. G. S. system. One foot-candle is one lumen per square foot and is equal to 1.0764 milliphots.

860 **Specific luminous radiation,** the luminous flux-density emitted by a surface, or the flux emitted per unit of emissive area. It is expressed in lumens per square centimeter.

Defining equation:

Let E' be the specific luminous radiation.

For surfaces obeying Lambert's cosine law of emission.

$$E' = \pi b_0.$$

863 **The Lambert, the C. G. S. Unit of Brightness,** the brightness of a perfectly diffusing surface radiating or reflecting one lumen per square centimeter. This is equivalent to the brightness of a perfectly diffusing surface having a coefficient of reflection equal to unity and illuminated by one phot.

864 **For most purposes, the millilambert** (0.001 lambert) is the preferable practical unit. A perfectly diffusing surface emitting one lumen per square foot will have a brightness of 1.076 millilamberts.

865 **Brightness expressed in candles per square centimeter** may be reduced to Lamberts by multiplying by π.

Brightness expressed in candles per square inch may be reduced to foot-candle brightness, by multiplying by the factor $144\,\pi = 452$.

Brightness expressed in candles per square inch may be reduced to lamberts by multiplying by $\pi/6.45 = 0.4868$.

In practise, no surface obeys exactly Lambert's cosine law of emission; hence the brightness of a surface in lamberts is, in general not numerically equal to its specific luminous radiation in lumens per square centimeter.

866 **Coefficient of reflection,** the ratio of the total luminous flux reflected by a surface to the total luminous flux incident upon it. It is a simple numeric. The reflection from a surface may be regular, diffuse or mixed. In perfect regular reflection, all of the flux is reflected from the surface at an angle of reflection equal to the angle of incidence. In perfect diffuse reflection, the flux is reflected from the surface in all directions, in accordance with Lambert's cosine law. In most practical cases, there is a superposition of regular and diffuse reflection.

867 **Coefficient of regular reflection** is the ratio of the luminous flux reflected regularly to the total incident flux.

868 **Coefficient of diffuse reflection** is the ratio of the luminous flux reflected diffusely to the total incident flux.

Defining equation:

Let m be the coefficient of reflection (regular or diffuse).

Then, for any given portion of the surface,

$$m = \frac{E'}{E}$$

2 A uniform source of one candle emits 4π lumens.

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869 **Lamp,** a generic term for an artificial source of light.

870 **Primary luminous standard,** a recognized standard luminous source reproducible from specifications.

871 **Representative luminous standard,** a standard of luminous intensity adopted as the authoritative custodian of the accepted value of the unit.

872 **Reference standard,** a standard calibrated in terms of the unit from either a primary or representative standard and used for the calibration of working standards.

873 **Working standard,** any standardized luminous source for daily use in photometry.

874 **Comparison lamp,** a lamp of constant but not necessarily known candle-power, against which a working standard and test lamps are successively compared in a photometer.

875 **Test lamp,** in a photometer,—a lamp to be tested.

876 **Performance curve,** a curve representing the behavior of a lamp in any particular (candle-power, consumption, etc.) at different periods during its life.

877 **Characteristic curve,** a curve expressing a relation between two variable properties of a luminous source, as candle-power and volts, candle-power and rate of fuel consumption, etc.

878 **Horizontal Distribution Curve.** A polar curve representing the luminous intensity of a lamp, or lighting unit, in a plane perpendicular to the axis of the unit, and with the unit at the origin.

879 **Vertical Distribution Curve.** A polar curve representing the luminous intensity of a lamp, or lighting unit, in a plane passing through the axis of the unit, and with the unit at the origin. Unless otherwise specified, a vertical distribution curve is assumed to be an *average* vertical distribution curve, such as may in many cases be obtained by rotating the unit about its axis and measuring the average intensities at the different elevations. It is recommended that in vertical distribution curves, angles of elevation shall be counted positively from the nadir as zero, to the zenith as 180 degrees. In the case of incandescent lamps, it is assumed that the vertical distribution curve is taken with the tip downward.

880 **Mean horizontal candle-power** of a lamp,—the average candle-power in the horizontal plane passing through the luminous center of the lamp.

It is here assumed that the lamp (or other light source) is mounted in the usual manner, or, as in the case of an incandescent lamp, with its axis of symmetry vertical.

881 **Mean spherical candle-power** of a lamp,—the average candle-power of a lamp in all directions in space. It is equal to the total luminous flux of the lamp, in lumens, divided by 4π.

882 **Mean hemispherical candle-power** of a lamp (upper or lower),—the average candle-power of a lamp in the hemisphere considered. It is equal to the total luminous flux emitted by the lamp, in that hemisphere, divided by 2π.

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883 **Mean zonal candle-power** of a lamp,—the average candle-power of a lamp over the given zone. It is equal to the total luminous flux emitted by the lamp in that zone, divided by the solid angle of the zone.

884 **Spherical reduction factor** of a lamp,—the ratio of the mean spherical to the mean horizontal candle-power of the lamp.[3]

885 **Photometric Tests** in which the results are stated in candle-power should be made at such a distance from the source of light that the latter may be regarded as practically a point. Where tests are made in the measurement of lamps with reflectors, the results should always be given as " apparent candle-power " at the distance employed, which distance should always be specifically stated.

886 **The output of all illuminants** should be expressed in lumens.

887 **Illuminants should be rated** upon a lumen basis instead of a candle-power basis.

888 **The specific output of electric lamps** should be stated in lumens per watt; and the specific output of illuminants depending upon combustion should be stated in lumens per b.t.u. per hour. The use of the term " efficiency " in this connection should be discouraged.

When auxiliary devices are necessarily employed in circuit with a lamp, the input should be taken to include both that in the lamp and that in the auxiliary devices. For example, the watts lost in the ballast resistance of an arc lamp are properly chargeable to the lamp.

889 **The Specific Consumption** of an electric lamp is its watt consumption per lumen. " Watts per candle " is a term used commercially in connection with electric incandescent lamps, and denotes watts per mean horizontal candle-power.

890 **Life Tests. Electric Incandescent Lamps** of a given type may be assumed to operate under comparable conditions only when their lumens per watt consumed are the same. Life-test results, in order to be compared, must be either conducted under, or reduced to, comparable conditions of operation.

891 **In Comparing Different Luminous Sources,** not only should their candle-power be compared, but also their relative form, brightness, distribution of illumination and character of light.

892 **Lamp Accessories. A reflector** is an appliance, the chief use of which is to redirect the luminous flux of a lamp in a desired direction or directions.

893 **A Shade is** an appliance, the chief use of which is to diminish or to interrupt the flux of a lamp in certain directions, where such flux is not desirable. The function of a shade is commonly combined with that of a reflector.

894 **A Globe is** an enclosing appliance of clear or diffusing materials, the chief use of which is either to protect the lamp, or to diffuse its light.

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3 In the case of a uniform point-source, this factor would be unity, and for a straight cylindrical filament obeying the cosine law it would be $\pi/4$.

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TABLE XIX.

Photometric Units and Abbreviations.

Photometric quantity	Name of unit	Abbreviations, Symbols and defining equations
1. Luminous flux	Lumen	$F.\ \Psi$
2. Luminous intensity	Candle	$I = \frac{dF}{d\omega}, \Gamma = \frac{d\Psi}{d\omega}$, cp.
3. Illumination	Phot., foot-candle, lux	$E = \frac{dF}{dS} = \frac{I}{r^2}\cos\theta.\beta$
4. Exposure	Phot-second	$t \quad E$
5. Brightness	Apparent candles per sq. cm.	$b = \frac{dI}{dS\ \cos\ \theta}$
	Apparent candles per sq. in.	
	Lambert	$L = \frac{dF}{dS}$
6. Normal brightness	Candles per sq. cm. Candles per sq. in.	$b_0 = \frac{dI}{dS}$
7. Specific luminous radiation	Lumens per sq. cm. Lumens per sq. in.	$E' = \pi b_0 \beta'$
8. Coefficient of reflection	—	$m = \frac{E'}{E}$
9. Mean spherical candlepower		scp
10. Mean lower hemispherical candlepower		lcp
11. Mean upper hemispherical candlepower		ucp
12. Mean zonal candlepower		zcp

13. 1 lumen is emitted by 0.07958 spherical cp.
14. 1 spherical candlepower emits 12.57 lumens.
15. 1 lux = 1 lumen incident per square meter = 0,0001 phot = 0.1 milliphot.
16. 1 phot = 1 lumen incident per sq. cm. = 10.000 lux = 1000 milliphot.
17. 1 milliphot = 0.001 phot = 0.929 foot-candle.
18. 1 foot-candle = 1 lumen incident per square foot = 1.076 milliphot = 10.76 lux.
19. 1 lambert = 1 lumen emitted per square centimeter.*
20. 1 millilambert = 0.001 lambert.
21. 1 lumen, emitted, per square foot* = 1.076 millilambert.
22. 1 millilambert = 0.929 lumen, emitted, per square foot*.
23. 1 lambert = 0.3183 candle per sq. cm. = 2.054 candles per sq. in.
24. 1 candle per sq. cm. = 3.1416 lamberts.
25. 1 candle per sq. in. = 0.4868 lamberts = 486.8 millilamberts.

*Perfect diffusion assumed.

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STANDARDS FOR TELEPHONY AND TELEGRAPHY

910 After careful consideration, it does not seem that the time is yet ripe for a formal standardization of terms and definitions used in telephony and telegraphy. Many of the terms commonly employed are used in more than a single way, and conversely, many pieces of apparatus and many constants which are essentially identical from a physical standpoint have been and are known by more than one designation.

911 **Damping of a Circuit.** The damping, at a given point, in a circuit from which the source of energy has been withdrawn, is the progressive diminution in the effective value of electromotive force and current at that point resulting from the withdrawal of electrical energy.

912 **Damping Constant.** The damping constant of a circuit depends upon the ratio of the dissipative to the reactive component of its impedance or admittance.

Applied to the admittance of a condenser or other simple circuit having capacity reactance, the damping constant for a harmonic electromotive force of given frequency is the ratio of the conductance of the condenser or simple circuit at that frequency, to twice the capacity of the condenser at the same frequency.

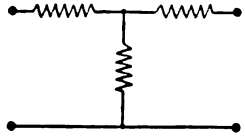
Applied to the reactance of a coil or other simple circuit having inductive reactance, the damping constant for a harmonic current of given frequency is the ratio of the resistance of the coil or circuit at that frequency, to twice the inductance at the same frequency.

913 **Equivalent Circuit.** An equivalent circuit is a simple network of series and shunt impedances, which, at a given frequency, is the approximate electrical equivalent of a complex network at the same frequency and under steady-state conditions.

NOTE: As ordinarily considered, the simple networks as defined are the electrical equivalents of complex networks only with respect to definite pairs of terminals, and only as to sending-end impedances, and total attenuation. A further requirement is that the only connections between the pairs of terminals are those through the network itself.

914 **"T" Equivalent Circuit.** A "T" equivalent circuit is a triple-star or "Y" connection of three impedances externally equivalent to a complex network.

Symbol:



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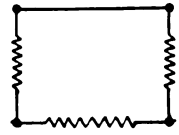
915 **"U" Equivalent Circuit.** A "U" equivalent circuit is a delta connection of three impedances externally equivalent to a complex network. It is also called a "Π" equivalent circuit.

Symbol:



IMPEDANCE

916 **Mutual Impedance.** The mutual impedance, for alternating currents, between a pair of terminals and a second pair of terminals of a network, under any given condition, is the negative vector ratio of the electromotive force produced between either pair of terminals on open circuit, to the current flowing between the other pair of terminals.

917 **Self Impedance.** The self impedance between a pair of terminals of a network, under any given condition, is the vector ratio of the electromotive force applied across the terminals to the current produced between them.

LINE CHARACTERISTICS

918 **Characteristic Impedance.** The characteristic impedance of a line is the ratio of the applied electromotive force to the resulting steady-state current upon a line of infinite length and uniform structure, or of periodic recurrent structure.

NOTE: In telephone practice, the terms (1) line impedance, (2) surge impedance, (3) iterative impedance, (4) sending-end impedance, (5) initial sending-end impedance, (6) final sending-end impedance, (7) natural impedance and (8) free impedance, have apparently been more or less indefinitely and indiscriminately used as synonyms with what is here defined as "characteristic impedance."

919 **Sending-End Impedance.** The sending-end impedance of a line is the vector ratio of the applied electromotive force to the resulting steady-state current at the point where the electromotive force is applied.

NOTE: See note under "Characteristic Impedance." In case the line is of infinite length of uniform structure or of periodic recurrent structure, the sending-end impedance and the characteristic impedance are the same.

920 **Propagation Constant.** The propagation constant per unit length of a uniform line, or per section of a line of periodic recurrent structure, is the natural logarithm of the vector ratio of the steady-state currents at various points separated by unit length in a uniform line of infinite length, or at successive corresponding points in a line of recurrent structure of infinite length. The ratio is determined by dividing the value of the current at the point nearer the transmitting end by the value of the current at the point more remote.

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921 **Attenuation Constant.** The attenuation constant is the real part of the propagation constant.

922 **Wave-Length Constant.** The wave-length constant is the imaginary part of the propagation constant.

LINE CIRCUITS

930 **Ground-Return Circuit.** A ground-return circuit is a circuit consisting of one or more metallic conductors in parallel, with the circuit completed through the earth.

931 **Metallic Circuit.** A metallic circuit is a circuit of which the earth forms no part.

932 **Two-Wire Circuit.** A two-wire circuit is a metallic circuit formed by two paralleling conductors insulated from each other.

933 **Superposed Circuit.** A superposed circuit is an additional circuit obtained from a circuit normally required for another service, and in such a manner that the two services can be given simultaneously without mutual interference.

934 **Phantom Circuit.** A phantom circuit is a superposed circuit, each side of which consists of the two conductors of a two-wire circuit in parallel.

935 **Side Circuit.** A side circuit is a two-wire circuit forming one side of a phantom circuit.

936 **Non-Phantomed Circuit.** A non-phantomed circuit is a two-wire circuit, which is not arranged for use as the side of a phantom circuit.

937 **Simplexed Circuit.** A simplexed circuit is a two-wire telephone circuit, arranged for the super-position of a single ground-return signalling circuit-operating over the wires in parallel.

NOTE: In view of the use of the term "Simplex Operation" in telegraph practice, it is felt that the designation "Simplexed Circuit" as applied to the arrangement described is not a happy one.

938 **Composited Circuit.** A composited circuit is a two-wire telephone circuit, arranged for the superposition on each of its component metallic conductors, of a single independent ground-return signalling circuit.

939 **Quadded or Phantomed Cable.** A quadded or phantomed cable is a cable adapted for the use of phantom circuits.

NOTE: The type of cable here defined has frequently been designated as "Duplex Cable"—a term which is objectionable, both on account of its lack of description and its widely different use in telegraph practice.

LOADING

950 **Loaded Line.** A loaded line is one in which the normal inductance of the circuit has been altered for the purpose of increasing its transmission efficiency for one or more frequencies.

951 **Series Loaded Line.** A series loaded line is one in which the normal inductance has been altered by inductance serially applied.

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952 **Shunt Loaded Line.** A shunt loaded line is one in which the normal inductance of the circuit has been altered by inductance applied in shunt across the circuit.

953 **Continuous Loading.** A continuous loading is a series loading in which the added inductance is uniformly distributed along the conductors.

954 **Coil Loading.** A coil loading is one in which the normal inductance is altered by the insertion of lumped inductance in the circuit at intervals. This lumped inductance may be applied either in series or in shunt.

NOTE: As commonly understood, coil loading is a series loading, in which the lumped inductance is applied at uniformly spaced recurring intervals

955 **Microphone.** A contact device designed to have its electrical resistance directly and materially altered by slight differences in mechanical pressure.

956 **Relay.** A relay is a device by means of which contacts in one circuit are operated under the control of electrical energy in the same or other circuits.

957 **Resonance.** Resonance of a harmonic alternating current of given frequency, in a simple series circuit, containing resistance, inductance and capacity, is the condition in which the positive reactance of the inductance is numerically equal to the negative reactance of the capacity. Under these conditions, the current flow in the circuit with a given electromotive force is a maximum.

958 **Retardation Coil.** A retardation coil is a reactor (reactance coil) used in a circuit for the purpose of selectively reacting on currents which vary at different rates.

NOTE: In telephone and telegraph usage, the terms "impedance coil," "inductance coil," choke coil" and "reactance coil" are sometimes used in place of the term "retardation coil."

959 **Skin Effect.** Skin effect is the phenomenon of the non-uniform distribution of current throughout the cross-section of a linear conductor, occasioned by variations in the intensity of the magnetic field due to the current in the conductor.

960 **Telephone Receiver.** A telephone receiver is an electrically operated device, designed to produce sound waves or vibrations which correspond in form to the electromagnetic waves or vibrations actuating it.

961 **Telephone Transmitter.** A telephone transmitter is a sound-wave or vibration-operated device designed to produce electromagnetic waves or vibrations which correspond in form to the sound waves or vibrations actuating it.

962 **The Coefficient of Coupling of a Transformer.** The coefficient of coupling of a transformer at a given frequency, is the vector ratio of the mutual impedance between the primary and secondary of the transformer, to the square root of the product of the self-impedances of the primary and of the secondary.

963 **Repeating Coil.** A term used in telephone practice meaning the same as transformer, and ordinarily a transformer of unity ratio.

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APPENDIX I.

STANDARDS FOR RADIO COMMUNICATION

The following Sections **1000** to **1028** have been abstracted from the report of the Standardization Committee of the Institute of Radio Engineers, and are here included by permission as an Appendix, until further revised. For full particulars, see the I.R.E. Standardization Committee report.

1000 Acoustic Resonance Device. One which utilizes, in its operation, resonance to the audio frequency of the received signals.

1001 Antenna. A system of conductors designed for radiating or absorbing the energy of electromagnetic waves.

1002 Atmospheric Absorption. That portion of the total loss of radiated energy due to atmospheric conductivity.

1003 Audio Frequencies. The frequencies corresponding to the normally audible vibrations. These are assumed to lie below 10,000 cycles per second.

1004 Capacitive Coupler. An apparatus which, by electric fields, joins portions of two radio frequency circuits, and which is used to transfer electrical energy between these circuits through the action of electric forces.

1005 Coefficient of Coupling (Inductive). The ratio of the effective mutual inductance of two circuits to the square root of the product of the effective self-inductances of each of these circuits.

1006 Direct Coupler. A coupler which magnetically joins two circuits having a common conductive portion.

1007 Counterpoise. A system of electrical conductors forming one portion of a radiating oscillator, the other portion of which is the antenna. In land stations a counterpoise forms a capacitive connection to ground.

1008 A Damped Alternating Current is an alternating current whose amplitude progressively diminishes.

1009 The Damping Factor of an exponentially damped alternating current is the product of the logarithmic decrement and the frequency.

Let I_0 = initial amplitude
I_t = amplitude at the time t
ϵ = base of Napierian logarithms
a = damping factor
Then: $I_t = I_0\, \epsilon^{-at}$

1010 Detector. That portion of the receiving apparatus which, connected to a circuit carrying currents of radio frequency, and in conjunction with a self-contained or separate indicator, translates

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the radio frequency energy into a form suitable for operation of the indicator. This translation may be effected either by the conversion of the radio frequency energy, or by means of the control of local energy by the energy received.

1011 Electromagnetic Wave. A periodic electromagnetic disturbance progressing through space.

1012 Forced Alternating Current. A current, the frequency and damping of which are equal to the frequency and damping of the exciting electromotive force.

1013 Free Alternating Current. The current following any electromagnetic disturbance in a circuit having capacity, inductance, and *less* than the critical resistance.

1014 Critical Resistance of a Circuit. That resistance which determines the limiting condition at which the oscillatory discharge of a circuit passes into an aperiodic discharge.

1015 Group Frequency. The number per second of periodic changes in amplitude or frequency of an alternating current.

NOTE 1. Where there is more than one periodically recurrent change of amplitude or frequency, there is more than one group frequency present.

NOTE 2. The term "group frequency" replaces the term "spark frequency."

1016 Inductive Coupler. An apparatus which, by magnetic forces, joins portions of two radio frequency circuits and is used to transfer electrical energy between these circuits, through the action of these magnetic forces.

1017 Linear Decrement of a Linearly Damped Alternating Current is the difference of successive current amplitudes in the same direction, divided by the larger of these amplitudes.

Let: I_n and I_{n+1} be successive current amplitudes in the same direction, of a linearly-damped alternating current.

Then: The linear decrement, $b = \dfrac{I_n - I_{n+1}}{I_n}$

Also: $I_t = I_0 (1 - bft)$

Where: I_0 = initial current amplitude
I_t = current amplitude at time t
f = frequency of alternating current

1018 Logarithmic Decrement of an exponentially damped alternating current is the logarithm of the ratio of successive current amplitudes in the same direction.

NOTE: Logarithmic decrements are standard for a complete period or cycle.

Let: I_n and I_{n+1} be successive current amplitudes in the same direction.

d = logarithmic decrement

Then: $d = \log_e \dfrac{I_n}{I_{n+1}}$

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1019 Radio Frequencies. The frequencies higher than those corresponding to the normally audible vibrations, which are generally taken as 10,000 cycles per second. See also Audio Frequencies.

NOTE: It is not implied that radiation cannot be secured at lower frequencies and the distinction from audio frequencies is merely one of definition based on convenience

1020 Resonance of a circuit to a given exciting alternating e.m.f. is that condition due to variation of the inductance or capacity in which the resulting effective current (or voltage) in that circuit is a maximum.

1024 A Standard Resonance Curve is a curve the ordinates of which are the ratios of the square of the current at any frequency to the square of the resonant current, and the abscissas are the ratios of the corresopnding wave length to the resonant wave length; the abscissas and ordinates having the same scale.

1026 Sustained Radiation consists of waves radiated from a conductor in which an alternating current flows.)

1027 Tuning. The process of securing the maximum indication by adjusting the time period of a driven element. (See Resonance.)

1028 A Wave-Meter, is a radio frequency measuring instrument, calibrated to read wave lengths.

1030 Decremeter. An instrument for measuring the logarithmic decrement of a circuit or of a train of electromagnetic waves.

1031 Attenuation, Radio. The decrease with distance from the radiating source, of the amplitude of the electric and magnetic forces accompanying (and constituting) an electromagnetic wave.

1032 Attenuation, Coefficient of (Radio). The coefficient, which, when multiplied by the distance of transmission through a uniform medium, gives the natural logarithm of the ratio of the amplitude of the electric or magnetic forces at that distance, to the initial value of the corresponding quantities.

1033 Coupler. An apparatus which is used to transfer radio-frequency energy from one circuit to another by associating portions of these circuits.

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APPENDIX II.

ADDITIONAL STANDARDS FOR RAILWAY MOTORS

1100 In comparing projected motors, and in case it is not possible or desirable to make tests to determine mechanical losses, the following values of these losses, determined from the averages of many tests over a wide range of sizes of single-reduction single-geared motors, will be found useful, as approximations. They include axle-bearing, gear, armature-bearing, brush-friction, windage, and stray-load losses.

TABLE XX
Approximate Losses in D-C. Railway Motors.

Input in per cent of that at nominal rating	Losses as per cent of input
100 or over	5.0
75	5.0
60	5.3
50	6.5
40	8.8
30	13.3
25	17.0

1101 The core loss of railway motors is sometimes determined by separately exciting the field, and driving the armature of the motor to be tested, by a separate motor having known losses and noting the differences in losses between driving the motor light at various speeds and driving it with various field excitations.

1102 Selection of Motor For Specified Service

The following information relative to the service to be performed, is required, in order that an appropriate motor may be selected.

(a) Weight of total number of cars in train (in tons of 2000 lb.) exclusive of electrical equipment and load.

(b) Average weight of load and durations of same, and maximum weight of load and durations of same.

(c) Number of motor cars or locomotives in train, and number of trailer cars in train.

(d) Diameter of driving wheels.

(e) Weight on driving wheels, exclusive of electrical equipment.

(f) Number of motors per motor car.

(g) Voltage at train with power on the motors—average, maximum and minimum.

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(h) Rate of acceleration in mi. per. hr. per second.
(i) Rate of braking (retardation in m. per hr. per second).
(j) Speed limitations, if any (including slowdowns).
(k) Distances between stations.
(l) Duration of station stops.
(m) Schedule speed including station stops in m.p.h.
(n) Train resistance in pounds per ton of 2000 pounds at stated speeds.
(o) Moment of inertia of revolving parts, exclusive of electrical equipment.
(p) Profile and alignment of track.
(q) Distance coasted as a per cent of the distance between station stops.
(r) Time of layover at end of run, if any.

1103 Stand-Test Method of Comparing Motor Capacity with Service Requirements: When it is not convenient to test motors under actual specific service conditions, recourse may be had to the following method of determining temperature rise.

1104 The essential motor losses affecting temperatures in service are those in the motor windings, core and commutator. The mean service conditions may be expressed, as a close approximation, in terms of that continuous current and core loss which will produce the same losses and distribution of losses as the average in service.

A stand test with the current and voltage which will give losses equal to those in service, will determine whether the motor has sufficient capacity to meet the service requirements. In service, the temperature rise of an enclosed motor (**§164**), well exposed to the draught of air incident to a moving car or locomotive, will be from 75 to 90 per cent (depending upon the character of the service) of the temperature rise obtained on a stand test with the motor completely enclosed and with the same losses. With a ventilated motor (**§165 and §167**), the temperature rise in service will be 90 to 100 per cent of the temperature rise obtained on a stand test with the same losses.

1105 In making a stand test to determine the temperature rise in a specific service, it is essential in the case of a self-ventilated motor (**§ 167**), to run the armature at a speed which corresponds to the schedule speed in service. In order to obtain this speed it may be necessary, while maintaining the same total armature losses, to change somewhat the ratio between the I^2R and core-loss components.

1106 Calculation for Comparing Motor Capacity with Service Requirements. The heating of a motor should be determined, wherever possible, by testing it in service, or with an equivalent duty cycle. When the service or equivalent duty-cycle tests are not practicable, the ratings of the motor may be utilized as follows to determine its temperature rise.

1107 The motor losses which affect the heating of the windings are as stated above, those in the windings and in the core. The former are proportional to the square of the current. The latter vary with the voltage and current, according to curves which can be supplied by the manufacturers. The procedure is therefore as follows:

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1108 (a) Plot a time-current curve, a time-voltage curve, and a time-core loss curve for the duty cycle which the motor is to perform, and calculate from these the root-mean-square current and the average core loss.

1109 (b) If the calculated r.m.s. service current exceeds the continuous rating, when run with average service core loss and speed, the motor is not sufficiently powerful for the duty cycle contemplated.

1110 (c) If the calculated r.m.s. service current does not exceed the continuous rating, when run with average service core loss and speed, the motor is ordinarily suitable for the service. In some cases, however, it may not have sufficient thermal capacity to avoid excessive temperature rises during the periods of heavy load. In such cases a further calculation is required, the first step of which is to compute the equivalent voltage which, with the r.m.s. current, will produce the average core-loss. Having obtained this, determine, as follows, the temperature rise due to the r.m.s. service current and equivalent voltage.

Let t = temperature rise
$p_0 = I^2R$ loss, kw.
p_c = core loss, kw.
} with r.m.s. service current, and equivalent service voltage.

T = temperature rise
$P_0 = I^2R$ loss, kw.
P_c = core loss, kw.
} with continuous load current corresponding to the equivalent service voltage.

Then

$$t = T \frac{p_0 + p_c}{P_0 + P_c}, \text{ approximately.}$$

1111 (d) The thermal capacity of a motor is approximately measured by the ratio of the electrical loss in kw. at its nominal (one-hour) capacity, to the corresponding maximum observable temperature rise during a one hour test starting at ambient temperature.

1112 (e) Consider any period of peak load and determine the electrical losses in kilowatt-hours during that period from the *electrical* efficiency curve. Find the excess of the above losses over the losses with r.m.s. service current and equivalent voltage. The excess loss, divided by the co-efficient of thermal capacity, will equal the extra temperature rise due to the peak load. This temperature rise added to that due to the r.m.s. service current, and equivalent voltage, gives the total temperature rise. If the total temperature rise in any such period exceeds the safe limit, the motor is not sufficiently powerful for the service.

1113 (f) If the temperature reached, due to the peak loads, does not exceed the safe limit, the motor may yet be unsuitable for the service, as the peak loads may cause excessive sparking and dangerous mechanical stresses. It is, therefore, necessary to compare the peak loads with the short-period overload capacity. If the peaks are also within the capacity of the motor, it may be considered suitable for the given duty cycle.

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APPENDIX III.

BIBLIOGRAPHY OF LITERATURE RELATING TO ELECTRICAL ENGINEERING STANDARDIZATION

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Bare and Insulated Wires and Cables

Aerial Cables
Annunciator Wire
Annunciator Cables
Automobile Horn Cord
Automobile Lighting Cables
Automobile Starter Cables
Automobile Charging Cables
Automobile Ignition Cables
Armature Coils
Armature Leads
Asbestos Braided Wire
Brush Cables
Border Light Cables
Brewery Cord
Battery Wire
Bridle Wire
Bare Copper Wire
Bare Copper Strands
Bare Braided Copper
Copper Wire, Bare
Copper Strands, Bare
Charging Cable for Electric Vehicles
Copper Clad, Rubber Insulated
Copper Clad Weatherproof
Cambric Cables
Canvasite Cord
Control Cable For Elevators
Car Wire And Cables
Cotton Tubing or Sleeving
Copper Sleeves
Copper Bells
Compound, Pothead No. 1
Compound, Splicing No. 2
Compound, Telephone No. 3
Drop Wire
Deck Cables
Electric Horn Cord
Electric Vehicle, Charging Cables
Electric Locomotive Cables
Elevator Annunciator Cables
Elevator Lighting Cables
Elevator Control Cables
Enameled Wire
Fixture Wire
Fireproof Wires
Flameproof Wire
Fire and Weatherproof Wire
Field Coils
Friction Tape
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